PB-232 958

COMPREHENSIVE MANAGEMENT OF PHOSPHORUS WATER POLLUTION

D. B. Porcella, et al

Utah Water Research Laboratory

Prepared for:

Environmental Protection Agency

February 1974

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

PB 232 958
W 74-08826

4. Comprehensive management of phosphorus water pollution,

7. D. B. Porcella, A. B. Bishop, J. C. Andersen, O. W. Asplund, A. B. Crawford, ~~W. J. Grenney, D. I. Jenkins, J. J. Jurinak, W. D. Lewis, E. J. Middlebrooks, R. M. Walkingshaw~~

9. Utah Water Research Laboratory, Utah State University, Logan, ~~Logan, Utah 84331~~

10. EPA Program Element ~~RFP WA72-A66~~ 1BA030

11. Contract 68-01-0728

~~Environmental Protection Agency~~

15. Environmental Protection Agency, Socioeconomic Studies Series report ~~number~~, EPA-600/5-74-010, February 1974. 411 p, 47 fig, 43 tab, 82 ref.

16. The environmental problems of phosphorus pollution are examined using an activity analysis approach to account for phosphorus inputs to surface waters. For purposes of analysis, this study assumes phosphorus to be the limiting factor in algal growth and eutrophication. A mass flow model, general enough to be applied to specific lakes or river basins, was developed in order to relate the flow of phosphorus from all activities in a basin to the consequences of eutrophication. Various control tactics to limit mass flow and thus eutrophication were defined from the standpoint of both supply and demand for phosphorus producing products and the management of phosphorus uses. Combinations of feasible controls designated as strategies, were applied to the model to determine the cost-effectiveness of the strategies in minimizing eutrophication. A hyper-eutrophic hypothetical lake basin, Lake Michigan, and Lake Erie were analyzed as case examples to test the model and control methods. Overall strategies were derived for the hypothetical lake and then applied to Erie and Michigan. In simple terms, phosphorus management strategies seemed feasible for control of eutrophication in present-day Lake Michigan while waste treatment together with management strategies was necessary for Lake Erie. (EPA)

17a. *Eutrophication, nutrients, ~~algal blooms~~, primary productivity, *Phosphorus, trophic levels, agriculture, industry, recreation, water quality, economics, lakes, ~~excise~~ taxes, Detergents, Waste water treatment, Water pollution control, *Lake Michigan, *Lake Erie, *Management

17b. ~~Costs, cost-benefit~~, cost-effectiveness, regional management, ~~phosphorus, detergents~~, *mass flow model, ~~waste treatment, runoff, mining~~, Excise taxes

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. 05C, 02H, 05G

Copy Available from GPO Sup Doc as EP1.23 600/5-74-010, $ 4.05;
microfiche from NTIS as PB
$1.45 MF / PB 232 958

18

429

Send To:

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D.C. 20240

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the SOCIOECONOMIC ENVIRONMENTAL STUDIES series. This series describes research on the socioeconomic impact of environmental problems. This covers recycling and other recovery operations with emphasis on monetary incentives. The non-scientific realms of legal systems, cultural values, and business systems are also involved. Because of their interdisciplinary scope, system evaluations and environmental management reports are included in this series.

EPA-600/5-74-010
February 1974

COMPREHENSIVE MANAGEMENT OF PHOSPHORUS WATER POLLUTION

by

D. B. Porcella, A. B. Bishop, J. C. Andersen,
O. W. Asplund, A. B. Crawford, W. J. Grenney,
D. I. Jenkins, J. J. Jurinak, W. D. Lewis,
E. J. Middlebrooks, R. M. Walkingshaw
Utah State University
Logan, Utah 84321

Contract No. 68-01-0728
Program Element 1BA030

Project Officer

Dr. Roger Don Shull
Implementation Research Division
Environmental Protection Agency
Washington, D. C. 20460

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D. C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $4.05

EPA REVIEW NOTICE

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The environmental problems of phosphorus pollution are examined using an activity analysis approach to account for phosphorus inputs to surface waters. For purposes of analysis, this study assumes phosphorus to be the limiting factor in algal growth and eutrophication. A mass flow model, general enough to be applied to specific lakes or river basins, was developed in order to relate the flow of phosphorus from all activities in a basin to the consequences of eutrophication. Various control tactics to limit mass flow and thus eutrophication were defined from the standpoint of both supply and demand for phosphorus producing products and the management of phosphorus uses.

Combinations of feasible controls, designated as strategies, were applied to the model to determine the cost-effectiveness of the strategies in minimizing eutrophication. An hypereutrophic hypothetical lake basin, Lake Michigan, and Lake Erie were analyzed as case examples to test the model and control methods. Overall strategies were derived for the hypothetical lake and then applied to Erie and Michigan using available information on these lakes. In simple terms, phosphorus management strategies seemed feasible for control of eutrophication in present-day Lake Michigan, while waste treatment together with management strategies were necessary for Lake Erie.

This report was submitted in fulfillment of Contract No. 68-01-0728 by Utah State University under the sponsorship of the Environmental Protection Agency. Work was completed as of June 30, 1973.

CONTENTS

		Page
EPA Review Notice		ii
Abstract		iii
List of Figures		vii
List of Tables		xi
Acknowledgments		xv

Sections

I	Summary and Conclusions	1
II	Recommendations	7
III	Introduction	10
IV	Eutrophication	22
V	Phosphorus Sources to Surface Waters	56
VI	Phosphorus Activity Analysis and the Mass Flow Model Overview	149
VII	Management Tactics for Controlling Phosphorus	195
VIII	Cost-Effectiveness Analysis of Strategies for Phosphate Management	261

CONTENTS (Continued)

References Cited 345

Bibliography [illegible]

Appendices [illegible]

FIGURES

No.		Page
1	General scheme for the stepwise solution to environmental problems	16
2	The derived demand for goods and services and side effects for phosphate intensive and other production activities	17
3	Phosphate source, use, and final destination with possible points of control	20
4	Diagram of aquatic system nutrient and energy flow	25
5	Maximum specific growth rate batch (μ_b) of Selenastrum capricornutum and the relation to initial phosphorus concentration (S_o) in PAAP medium (μ_b calculated from absorbance measurements)	29
6	Relationship between maximum cell concentration (X, mg SS/1) and the initial concentration of phosphorus (S_o)	30
7	Correlation between concentrations of soluble nitrate and phosphate in eutrophic lakes (A, B, C, from Stumm and Leckie (1970); D from Edmundson (1972))	33
8	Spring concentrations of total phosphorus apparently are related to total phosphorus loading (from Vollenweider, 1968)	44
9	Average spring-summer phosphorus flow in Hyrum Reservoir, April 4 to November 4, 1971	45

FIGURES (Continued)

No.		Page
10	Chlorophyll a concentration appears related to winter orthophosphate and summer total phosphorus concentrations	48
11	Relative eutrophication in lakes having different mean depths	53
12	Simplified present-day mass flow diagram for phosphorus in the USA	57
13	Activity analysis for phosphate indicating the major pathways to any lake for the most typical uses	60
14	Vertical distribution of extractable phosphorus in control and surface applied phosphorus fertilized soil in Wisconsin	69
15	Sales history of soaps and detergents	88
16	Location of major phosphoric acid plants in the United States (taken from Fullam and Faulkner, 1971)	116
17	Flowsheet for lime neutralization of gypsum pond water (Adapted from Fullam and Faulkner, 1971)	117
18	Primary calculated outputs from the phosphorus mass flow model	150
19	Diagram of the phosphorus distribution used to program the effect of phosphorus fertilizer application on the phosphorus load of surface waters	158
20	Treatment methods that have been applied to animal manures and feedlot runoff	169
21	Flow diagram for subroutine TREAT	173
22	Schematic diagram showing unit processes associated with common phosphorus removal systems	174
23	Percent phosphorus removal vs. applied molar ratio Fe/P	177

FIGURES (Continued)

No.		Page
24	Capital costs for tertiary chemical coagulation	179
25	Selective ion exchange	180
26	Total costs for reverse osmosis treatment of municipal effluent	182
27	Total costs for reverse osmosis treatment of industrial effluent	183
28	Applicable control methods for phosphorus generating activities	197
29	Control points superimposed on the phosphorus activity analysis showing the major application points for pertinent control tactics (see Table 37)	198
30	Control tactics applied to urban and rural watersheds and domestic wastes	202
31	Control tactics applied to agriculture	203
32	Control tactics applied to animal waste production	204
33	Control tactics applied to the industrial sector	205
34	Control tactics applied to mining wastes	206
35	Control points superimposed on the phosphorus activity analysis showing the major application points for effluent controls (see pp. 247-250)	248
36	Phosphorus discharges are related to damages and control costs	264
37	Cost-benefits and cost-effectiveness analysis related to phosphorus mass flow	266

FIGURES (Continued)

No.		Page
38	Example cost-effectiveness curves	273
39	Hypothetical Lake--relative contributions from phosphorus activities prior to application of controls	276
40	Lake Erie--relative contributions from phosphorus activities prior to application of controls	277
41	Lake Michigan--relative contributions from phosphorus activities prior to application of controls	278
42	Hypothetical Lake--effects of control on relative eutrophication (see text for description)	281
43	Lake Erie--effects of controls on relative eutrophication (see text for description)	282
44	Lake Michigan--effects of controls on relative eutrophication (see text for description)	283
45	Hypothetical lake--cost-effectiveness of various treatment levels in relation to eutrophication based on available phosphorus loading	291
46	Lake Erie (20 m mean depth)--cost-effectiveness of various treatment levels in relation to eutrophication based on available phosphorus loading	292
47	Lake Michigan--cost-effectiveness of various treatment levels in relation to eutrophication based on available phosphorus loading	293

TABLES

No.		Page
1	Selected Water Systems in North America in Relation To An Estimation of the Limiting Nutrient	38
2	Methods of Controlling Eutrophication and Its Effects	40
3	Improvement in Eutrophication Effects Resulting from Decrease in Nutrient Input	42
4	Phosphorus Consumption in the USA	59
5	Effect of Management Practice (Prevailing and Improved) and Corn Crop on Runoff in a 4-Year Rotation	74
6	Estimated Annual Amounts of Constituents in Runoff from Rural Land as Affected by Management Practice (Prevailing or Improved) and Cover Crop	75
7	Nitrogen and Phosphorus Balance in Tile Drained Soils	76
8	Sales of Organophosphorus Pesticides (U.S. Tariff Commission)	80
9	1970 Estimated Distribution of Phosphorus by Product Class of All Detergents/Cleaners	89
10	Total U.S. Production of Selected Phosphate Chemical (1970)	90
11	Costs Associated with 90 Percent Total Phosphorus Removal from Raw Wastewater (Weber et al., 1970)	96

TABLES

No.		Page
1	Selected Water Systems in North America in Relation To An Estimation of the Limiting Nutrient	38
2	Methods of Controlling Eutrophication and Its Effects	40
3	Improvement in Eutrophication Effects Resulting from Decrease in Nutrient Input	42
4	Phosphorus Consumption in the USA	59
5	Effect of Management Practice (Prevailing and Improved) and Corn Crop on Runoff in a 4-Year Rotation	74
6	Estimated Annual Amounts of Constituents in Runoff from Rural Land as Affected by Management Practice (Prevailing or Improved) and Cover Crop	75
7	Nitrogen and Phosphorus Balance in Tile Drained Soils	76
8	Sales of Organophosphorus Pesticides (U.S. Tariff Commission)	80
9	1970 Estimated Distribution of Phosphorus by Product Class of All Detergents/Cleaners	89
10	Total U.S. Production of Selected Phosphate Chemical (1970)	90
11	Costs Associated with 90 Percent Total Phosphorus Removal from Raw Wastewater (Weber et al., 1970)	96

TABLES (Continued)

No.		Page
12	Costs Associated with Phosphorus Removal from Raw Wastewater by Lime Coagulation, Two-Stage Clarification and Additional Advanced Processes (Bishop et al., 1972)	97
13	Costs Associated with 80 Percent Removal of Total Phosphorus from Raw Wastewater in Conventional Treatment Facilities (Convery, 1970)	99
14	Costs Associated with Lime Treatment of Secondary Effluent (EPA, 1971a; Culp and Culp, 1971; Smith and McMichael, 1969)	103
15	Costs Associated with Alum Coagulation (with Polymer) of Secondary Effluent	105
16	Estimated Costs for a 10 mgd Ion Exchange Plant (Dryden, 1970)	107
17	Estimated Costs for a 1 mgd Selective Ion Exchange Plant (EPA, 1970a)	107
18	Estimated Costs for a 10 mgd Reverse Osmosis Plant (Dryden, 1970)	109
19	Cost Estimates for Reverse Osmosis (Besik, 1971)	109
20	Estimated Costs for a 10 mgd Electrodialysis Plant (Dryden, 1970)	111
21	Industrial Uses of Phosphorus in 1968 Based on Lewis (1970) and Logue (1958)	113
22	Physical Characteristics of Livestock Defecation	124
23	Nutrient and Sanitary Characteristics of Domestic Fowl Manures	126

TABLES (Continued)

No.		Page
24	Nutrient and Sanitary Characteristics of Swine Manures	126
25	Nutrient and Sanitary Characteristics of Cattle Manures	127
26	Nutrient and Sanitary Characteristics of Sheep Manures	129
27	Feedlot Runoff Characteristics	133
28	Estimate of Nutrient Contributions from Various Sources (Goldberg, 1970)	136
29	Annual Nutrient Loss for Two Seasons for the Natural-Rainfall Erosion Plots (Timmons et al., 1968)	137
30	Ranges of Some Selected Nutrients in Sewage Effluents and Land Drainage Entering the Great Ouse: Concentrations in the River Water are also Included (Owens and Wood, 1968)	138
31	Mean Nutrient Concentrations from Runoff Sources in Parts per Billion (Sylvester, 1961)	139
32	Soluble Phosphorus Concentrations Reported for Waters Draining Rural Watersheds (Verduin, 1967)	140
33	Nutrient Losses from Lancaster, Wisconsin, Plots on January 23 and 24, 1967 from Snowmelt and Rains (Minshall et al., 1970)	143
34	Average Concentrations of Pollutants in Runoff Before and After Percolation through 30 Inches of Soil Growing Crops as Shown (Wells et al., 1970)	145
35	Representative Example of Program Output Showing Phosphorus Activity Analysis, Mass Flow and Relative Eutrophication	190

TABLES (Continued)

No.		Page
36	Important Variable Parameters in Phosphorus Input to Surface Waters Program (Completes Inputs Listed in Appendix D)	194
37	Summary Listing of Control Tactics	200
38	Estimated Dry Weight of All Detergents Consumed per Person in the United States	213
39	Revenue from Detergent Excise Tax at Different Rates and Elasticities (1967 Data)	214
40	Revenue from Detergent Excise Tax at Different Rates and Elasticities (Estimated 1973 Data)	215
41	Summary Listing of Control Tactics	268
42	Cost Savings Attributable to Strategies for Lake Erie Case	297
43	Analysis of Excise Tax on High Phosphate Detergents--Lake Erie Example	301

ACKNOWLEDGMENTS

Unfortunately, there is no accurate way of giving equivalent credit in relation to effort and contribution to the members of this project. A multidisciplinary project as broad in scope as this one can only be considered an exercise in group intraeducation. Consequently, except for the first two authors who directed the project, authors are listed in alphabetical order. All coauthors are from Utah State University except David I. Jenkins, Department of Sanitary Engineering, University of California, Berkeley. We also appreciate very much the guidance and encouragement of the project officer, Roger Don Shull, Environmental Protection Agency. In addition to these persons, acknowledgment of significant contributions must be made to Paul Uttormark, University of Wisconsin Water Resources Center, Yacov Haimes Case Western Reserve University, and James R. Duthie, Procter and Gamble.

Mrs. Janet Rogers suffered through 11 styles of multidisciplinary handwriting to type this report. Also, other staff of the Utah Water Research Laboratory (Jay M. Bagley, Director) and the Utah State University deserve acknowledgment.

SECTION I
SUMMARY AND CONCLUSIONS

This study represents the development of an approach for analyzing and assessing the impact of pollutants on surface waters (or any other ecosystem) and determining the cost-effectiveness of implementing control methods and strategies.

The approach developed consists of an activity analysis of producing and consuming sectors which mobilize the pollutant so that it may enter or be discharged to receiving media. A mass flow model accounts for actual pollutant loadings from the various activities based on a set of parameters which describe each activity's output.

In particular, this study focused on phosphorus pollution in surface water under the assumption that it is the limiting factor in algal growth and lake eutrophication. Phosphorus does not limit algal productivity in all lakes and commonly phosphorus is not the limiting factor in the eutrophication of streams and marine coastal waters.

An activity analysis was formulated as a general phosphorus mass flow model which could be applied to any river basin. The model was tested and operated for three case examples: A hypothetical basin, Lake

Michigan, and Lake Erie. No laboratory or field experimental work was performed on this project. The information presented is the result of library research and the coordination of technical, economic, and sociological information on phosphorus uses, sources, treatments, cost relationships, and management schemes.

The first step was to analyze the role of phosphorus in eutrophication of surface waters and to develop a relationship between phosphorus input to a body of water and the resultant level of eutrophication. Algal growth and phosphorus concentrations for both laboratory and field studies showed a linear relationship as long as phosphorus alone was limiting. Methods of defining and measuring the limiting nutrient were described and surface waters where such information previously existed were listed. The Great Lakes, particularly Lakes Michigan and Erie, were determined as representative water bodies where phosphorus was the probable limiting nutrient. The relationship between algal population density and hence eutrophication and annual phosphorus loading ($g/m^2 \cdot yr$) as developed by Vollenweider (1968) was used to relate phosphorus input and eutrophication. Although further work on this relationship is needed, it represents a simple yet intuitively useful representation of the actual pollution problem which is eutrophication.

The next step was to describe the cultural activities and natural phosphorus sources which result in phosphorus input to surface waters. This description, an activity analysis, was used at a later point in the development of phosphorus control strategies to determine the controls which would be most effective in reducing eutrophication. Basically, sources were divided into two groups: Natural and man-caused or cultural. Then sources were further divided into diffuse and point sources. The activities were also classified into one of the following seven categories: (1) Nonbasin activities (rainfall on the lake, river flow into the basin from another basin, groundwater as a source and as a recipient; groundwater was discussed but not included in the analysis); (2) agriculture (fertilizer and pesticide use, irrigation return flows); (3) urban and rural watersheds (solid waste disposal, managed forests, grazed watersheds, undisturbed and developed natural watersheds, urban runoff); (4) domestic wastes (human wastes, detergent phosphorus); (5) industrial wastes (industrial detergents, water softeners, miscellaneous industrial uses, metal finishing, food wastes); (6) mining (phosphorus mining activities, runoff from strip mining); and (7) animal production (animal wastes from cattle, poultry, pigs, sheep). These uses were related to the ultimate source of phosphorus.

Ultimately, all of the phosphorus used by society comes from the phosphorus mining industry. In 1968 mined phosphorus was distributed approximately as follows: 76 percent to phosphorus fertilizers, 3 percent to animal feeds, 7 percent to detergents, 3 percent to metal finishing, and 11 percent to other miscellaneous, largely industrial, uses. Thus these distributions provided an initial estimate of the best control points. However, the distribution among uses is deceptive and actual inputs to surface waters needed to be described to determine the important and feasible control points.

A mass flow model was constructed which calculates the input quantities from the major phosphorus producing sources to surface waters. This particular model is simple, requires minimal input information, and calculates the relative eutrophication as a function of available phosphorus input loading ($g/m^2 \cdot yr$). Because of its simplicity it is relatively easy to use, but, consequently, care must be taken that the simplicity does not lead to erroneous conclusions.

A broad range of control methods (tactics) were described and analyzed as to where they can be used in the phosphorus flow system to reduce or eliminate phosphorus inputs from the activity sectors. The control tactics were considered in detail including: (1) Supply and demand controls such as subsidies, excise taxes, and content labeling; (2) resource controls (mining restrictions, etc.); (3) methods for management of phosphorus uses (resource and product substitution, recycling and reclamation, etc.); (4) management of phosphorus discharges including both point and diffuse sources, for example, land management and use practices and controls, pollution standards, and effluent changes; (5) judicial regulation including class action, judicial review and common law remedies; (6) wastewater treatment technology; and (7) in lake treatment techniques and lake modification. Not all tactics were considered equally feasible and some were rejected outright. Other tactics were considered feasible under some circumstances but not under others. The category of control tactics estimated as feasibly restricting of phosphorus input to surface waters were combined to develop management strategies.

In the last section of the report (Section VIII) the mass flow model was used to test the combinations of control tactics woven into the different management strategies and to determine the relative level of effectiveness of the management strategies in reducing eutrophication. The levels of effectiveness achieved were then examined in relation to the costs for implementation of the management strategy. Only treatment costs could be considered within the scope of the research, although other real costs associated with management strategies were identified and the cost-effectiveness analysis was structured so they could be effectively included.

The particular management strategies studied were treatment of municipal wastes to remove phosphorus, utilization of non- or low phosphate detergents, land management of phosphorus to minimize eroded phosphorus, animal waste disposal controls, minimization of urban runoff and industrial uses of phosphorus, and the sewering of all combined sewers and direct discharges so that the waste entered municipal treatment plants.

Different strategies resulted in differing levels of effectiveness of phosphorus input minimization depending on the particular basin studied. Thus, detergent phosphorus control and advanced waste treatment for phosphorus removal might be sufficient to reduce eutrophication in a particular basin and be of little effect in another; a combination of land use strategies and waste treatment might be effective in a third, or required to reach an acceptable level of plant production. These considerations reinforce the necessity for regional planning to prevent counter-productive solutions being applied in water supply basins (or other units).

The costs associated with such analyses were restricted primarily to treatment costs; a method was explained where relative costs could be compared as necessary to allow decision makers to identify "cost-effective decision" in selecting appropriate management strategies.

The results of the study point to two overall conclusions, one specific and one general. Specifically, the case studies and analysis using the phosphorus mass flow model demonstrate that the model has general application for analyzing the phosphorus pollution problems of any river basin, and in the hands of planners can be a useful tool in assessing the impact of various proposed management strategies for control of phosphate pollution in the basin. Generally, the usefulness of the activity analysis approach developed for analysis of phosphorus pollution indicated that it could be applied in analyzing the impact of any pollutant on an ecosystem and in an examination of the most effective strategies for management control. The example case studies indicated that phosphorus uses management strategies seemed feasible for control of eutrophication in present-day Lake Michigan, while waste treatment for phosphorus removal together with management strategies were necessary for Lake Erie.

SECTION II
RECOMMENDATIONS

The following recommendations generally point to areas where more research and better quantitative data are needed to improve the results of the study. In addition it is proposed that the method described in this report be applied to specific basins.

1. Planning and management data for river basins. Information which can be utilized in the mass flow model should be compiled for each river basin in the country. Such data would be useful not only to this activity analysis, but to similar analyses applied to other pollutants (pesticides, nitrogen, BOD, toxic metals). Some examples of necessary input data would include human populations, animal numbers and types, and land use area definition. The compendium would be similar in scope to that of the Water Resources Council (1968).
2. Cost-effectiveness and economic analysis. While the cost analysis dealt effectively with treatment costs, further study needs to be undertaken in order to develop estimates of the real costs of strategy implementation to be incorporated into the cost-effectiveness analysis. Work should also be undertaken in defining the benefit side of pollution control

measures, initially through the development of pollution damage functions.

3. The relationship between loading and eutrophication. Functional relationships between pollutional parameters and pollutional effects are necessary to perform analyses such as in this report. This should include a better understanding of physical, chemical, and biological interactions. Establishing these relationships and then demonstrating their actual existence is extremely difficult. Their development should relate concentrations, loading, and mass emission rates where possible. At least the first steps should be taken to develop others similar to those for nitrogen and phosphorus.
4. Phosphorus analysis. The fate of phosphorus in terrestrial and aquatic ecosystems needs to be better understood in order to: (1) Estimate the availability of phosphorus to plant growth no matter what its source; (2) quantitatively estimate growth response to its addition; and (3) determine sinks for phosphorus where it can be considered unavailable for recycle.

The development of these research areas would contribute materially to refinement of the model and the analytical approaches developed in this research, and are suggested as worthwhile follow-on programs to this study.

Furthermore it is recommended that other river basins and target lakes should be analyzed using this approach in order to define possible control strategies and legislation for eutrophication control. Such analysis will define the feasibility of this approach for economical phosphorus control but extend its possible application to other types of pollutants and problems.

SECTION III

INTRODUCTION

SCOPE AND OBJECTIVES OF STUDY

Phosphorus is a nonmetallic element absolutely required for all forms of life. In nature it is primarily observed as phosphate minerals but is chiefly available for the natural plant and animal communities of aquatic systems as orthophosphate. Because of limited availability and of solubility in aqueous solutions of the geological matrix, phosphates are quite often a limiting factor for both aquatic and terrestrial natural ecosystems. The addition of phosphorus to such ecosystems by human society frequently leads to increased productivity. However, whereas in agriculture the addition of phosphorus to terrestrial ecosystems is frequently necessary and of beneficial use, phosphorus and other nutrients frequently are introduced to aquatic ecosystems along with waste materials. This fertilization and resulting increased productivity in the aquatic ecosystem leads to conditions which decrease the beneficial uses of the water. Limitation of phosphorus inputs to surface waters is considered a practical means for restoring beneficial uses to aquatic ecosystems. However, such ecosystems are extremely complex and require complete analysis to ensure that proposed changes in various inputs and their controls will in fact lead to the result which is intuitively expected (Forrester, 1971).

Environmental management of particular resources implies that the particular system within which a resource is distributed is well understood and the mechanisms of distribution are well known. The phosphorus resource is relatively well described; phosphorus control is of interest because of its important role in the development of eutrophic conditions in lakes. Because of this role many suggestions have been made towards the elimination of some of the phosphorus input to surface waters and thus the control of eutrophication. These proposed methods have included phosphorus removal from detergent formulations, removal of phosphorus from domestic wastes, and the application of the concept of zero discharge from point sources. These manipulations of phosphorus input are considered rather simplistic solutions of complex problems and immediately one questions first, whether these kinds of manipulations will produce improvement in the conditions, and second, whether in fact these solutions may be counter-productive in terms of the total economy of the region or nation involved.

Thus it was assumed at the beginning of this study that a relatively complete understanding of phosphorus cycling in the social-technical-ecological system would allow the development of a strategy for phosphorus control which would decrease eutrophication effects at a minimum cost. Thus, benefits would be maximized in relationship to costs. Because of the difficulty in quantitating the economic values of various benefits, this kind of study is forced to approach the problem from a cost-effectiveness point of view, i. e., to maximize the effectiveness of control of phosphorus input to surface waters at least cost. Therefore, many of the decisions that have been made in this study as to how to approach phosphorus control have been made with this constraint in mind. Evaluation of benefits of phosphorus restriction in natural waters, then, must be an intuitive judgment based on best available knowledge.

A last major consideration was the time scale for implementation. Long-term solutions or merely hypothetical and proposed (untried) controls were only mentioned and not woven into the overall strategy.

Therefore, the objectives of this study were first to describe the system in which phosphorus is utilized, second, to determine the possible alternatives for controlling phosphorus input to surface waters, and third, to find the least-cost strategy for controlling that phosphorus input.

Specifically, to achieve the objectives described above, the following areas were studied:

I. Environmental damages caused by release of phosphorus:
    1. General discussion of eutrophication
    2. Concept of multiple limiting factors
    3. Evidence of phosphorus causality
    4. Concentration relationship between phosphorus and algae
    5. Definition of critical phosphorus levels
    6. Feasibility of phosphorus control resulting in eutrophication control

II. The major sources of phosphorus to aquatic systems:

1. Natural runoff (includes direct precipitation)
2. Agricultural
    a. fertilizers
    b. animal wastes
    c. irrigation drain waters
    d. irrigation tail waters
    e. agricultural land runoff
    f. phosphorus-based pesticides;
3. Municipal wastes
    a. human and domestic wastes
    b. detergents
    c. urban runoff;
4. Industrial
    a. mining operations
    b. detergent
    c. phosphorus acid uses
    d. industrial wastes
    e. water softening;

III. The relationship between phosphorus sources and surface water phosphorus concentrations (to be applied to basin or subbasin):

1. Mass balance approach using numbers obtained from literature
2. Relative importance of various sources
3. Relative importance of various "controllable" sources
4. Effect of natural removal systems
5. Beneficial effects of phosphorus control on related parameters
6. Relation of phosphorus level to one use or multiuse concepts

IV. Major uses of phosphorus by society and their relative and quantitative role in the phosphorus mass balance:

1. Fertilizers
2. Detergents--domestic and industrial
3. Human nutrition
4. Animal nutrition
5. Accelerated erosion
6. Mining and industrial uses

V. Possible control measures, their feasibility and costs:

1. Detergent changes
2. Fertilizer management changes
3. Advanced waste treatment of municipal and industrial wastes
4. Product modifications other than for detergents
5. Controls over land use, mine wastes, etc.
6. Evaluation of bottom sediments and suspended sediments as a source or sink of phosphorus
7. Evaluation of treatment methods for removal of other wastewater parameters (e.g., BOD) as incidental methods for phosphorus removal

VI. Relation of uses to benefits and to the requirements for phosphorus use. This will allow the proper estimation of trade offs, etc. For example:

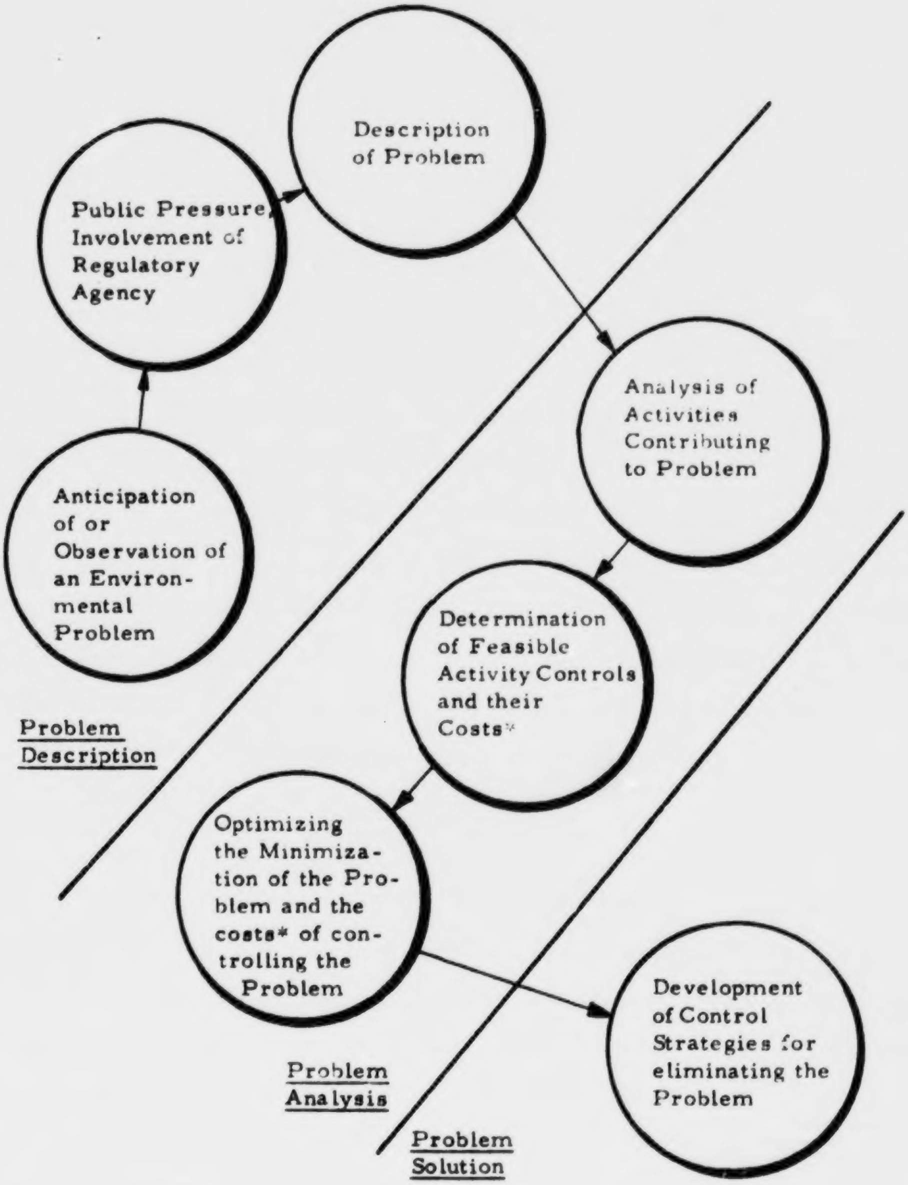
1. Increased land use vs. intensive phosphorus application to small land areas
2. "Whiter clothes, cleaner dishes, automated food handling" vs. less of the same
3. Stricter treatment standards for human and animal wastes vs. source control

VII. Analysis of the above controls in terms of actual lake systems.

NATURE OF THE PROBLEM

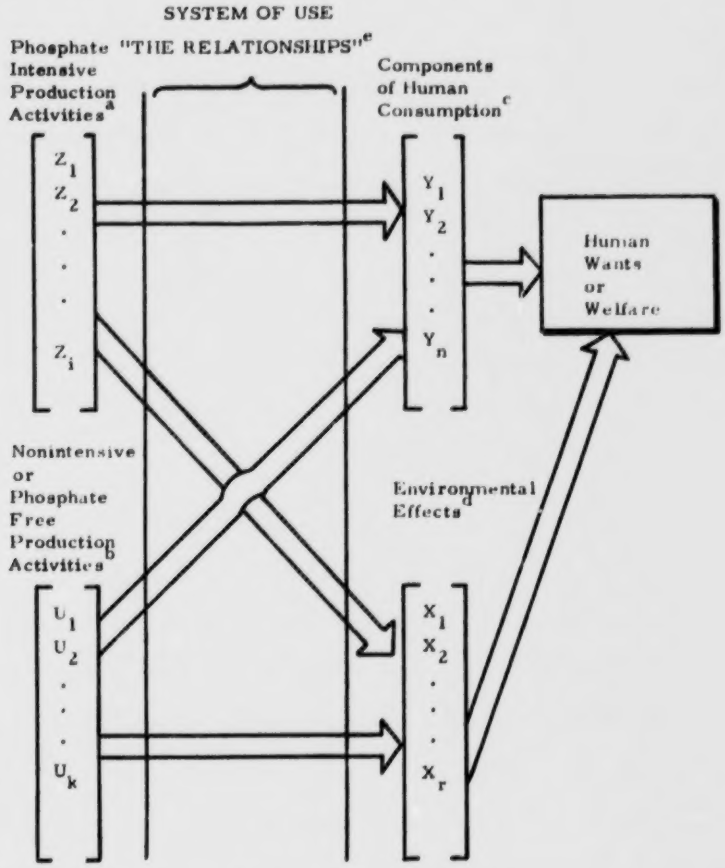
As can be seen in Figure 1, a particular environmental problem can be broken down to three general phases, problem description, analysis, and solution. Each of these general phases can be further broken down into several subphases. In the case of the phosphorus problem in the environment, i. e., the development of eutrophic lakes, much of the "observation of the problem," "development of public pressure and regulations," and "description of the problem" has largely been accomplished. Although the implication that phosphorus is the sole factor involved in the problem of eutrophication is incorrect, the development of the analysis described in this study has been predicted on the assumption that control of phosphorus will to some extent allow control of eutrophication. The reasons for this assumption are described in later chapters.

A large part of the phosphorus (as well as most other pollutants) which is found in surface waters results from human activity. Naturally high concentrations of phosphorus occur only in unique circumstances. Human demands for goods and services give rise to production processes and facilities which mobilize the basic materials found in nature. In Figure 2, the box on the right of the page represents human wants. The necessities and comforts of life which contribute to human welfare can be enumerated and are designated as Y_n. These are the motivators for all activities, as designated by the black arrows that go "through the production systems," and are the individual components of human wants.


Description of Problem
Public Pressure, Involvement of Regulatory Agency
Anticipation of or Observation of an Environmental Problem
Analysis of Activities Contributing to Problem
Determination of Feasible Activity Controls and their Costs*
Optimizing the Minimization of the Problem and the costs* of controlling the Problem
Development of Control Strategies for eliminating the Problem
Problem Description
Problem Analysis
Problem Solution

*"Costs" include technological, implementation, and social costs.

Figure 1. General scheme for the stepwise solution to environmental problems.


SYSTEM OF USE
Phosphate Intensive Production Activities[a]
"THE RELATIONSHIPS"[e]
Components of Human Consumption[c]
Z_1
Z_2
Z_i
Y_1
Y_2
Y_n
Human Wants or Welfare
Nonintensive or Phosphate Free Production Activities[b]
Environmental Effects[d]
U_1
U_2
U_k
X_1
X_2
X_r

[a] Z_i = phosphate base detergents, phosphate fertilizer, etc.

[b] U_k = soaps, non-use, etc.

These are instruments with which the system can be altered

[c] Y_n = Food, fiber, shelter, industrial goods, services, etc.

[d] X_r = Effects on land, air and water (impact can be positive or negative)

These are targets which generally define the desired high level of consumption and desired low level of environmental deterioration. Tradeoffs among these are generally available

[e] This set of relationships is defined by production functions which relate the inputs of labor, capital, and raw materials to the outputs of both "goods" which are consumed, and the "bads" which are the detrimental environmental effects imposed on people as they use the environment.

Figure 2. The derived demand for goods and services and side effects for phosphate intensive and other production activities. (Classification based on Tinbergen, 1962.)

In most cases these Y_n can be produced by various alternative processes. For simplicity, these are divided into two groups with respect to production of phosphate concentrations, the Z_i list of activities which are intensive (e. g. , phosphate detergents) and the other nonintensive (U_k) activities (e. g. , nonphosphate or low phosphate detergents). These activities meet the demands for goods and services through the economic system.

Each of these Z and U type activities gives rise to effects on the air, land, and water components of the environment (X_r). The nature of these relationships is also represented in the center part of Figure 2. This environmental effect, in turn, has direct impacts on human welfare. The system of relationships defines the output of the desired goods and services as well as the environmental impacts associated with inputs of various combination factor inputs. Much of the work of this project is concerned with altering the proportions of components of wants or welfare that are produced by phosphate intensive as compared to other activities, diverting the adverse effects on environmental factors that arise from the production activities, and minimizing the adverse effects of the environmental degradations that are not practically avoidable by sequestration, changing locations, and other measures. A key point of this figure is that the process of degradation arises mainly from meeting human wants and needs. The satisfaction of these wants and needs must remain a major factor of consideration as control and management measures are devised.

BASIC MODEL OF THE CONCENTRATION PROCESS

One of the terms most frequently used in the environmental movement is "recycle." This is an important aspect of the available control and management possibilities, as shown in Figure 3. Once phosphate is mobilized from its original source, the number of times of use or the "round-aboutness" with which the material enters into final receiving waters becomes an important determinant of how much actually enters the water. Three general points of control can be exercised. The first is at the source, where the amount brought into the production system is controlled. Another is at some (possibly several) point before final disposition, where the amount which is allowed to leave the production system is either stored or controlled to divert the material back into the production process (recycled). The third is the possibility of (1) diverting the effluent to a sink rather than letting it enter the environment of a water course or lake; or (2) to cause it to enter a sink in the lake itself. Basically, all control and management systems fall into these three categories.

METHOD OF ANALYSIS

The project was divided into several phases. First, the mass balance of phosphorus uses and resultant inputs to surface waters was developed. Then possible control strategies and possible methods of implementing these control strategies were defined. The mass balance analysis then was reevaluated and control technology and implementation strategies again defined in the light of the reevaluation. This feedback effect

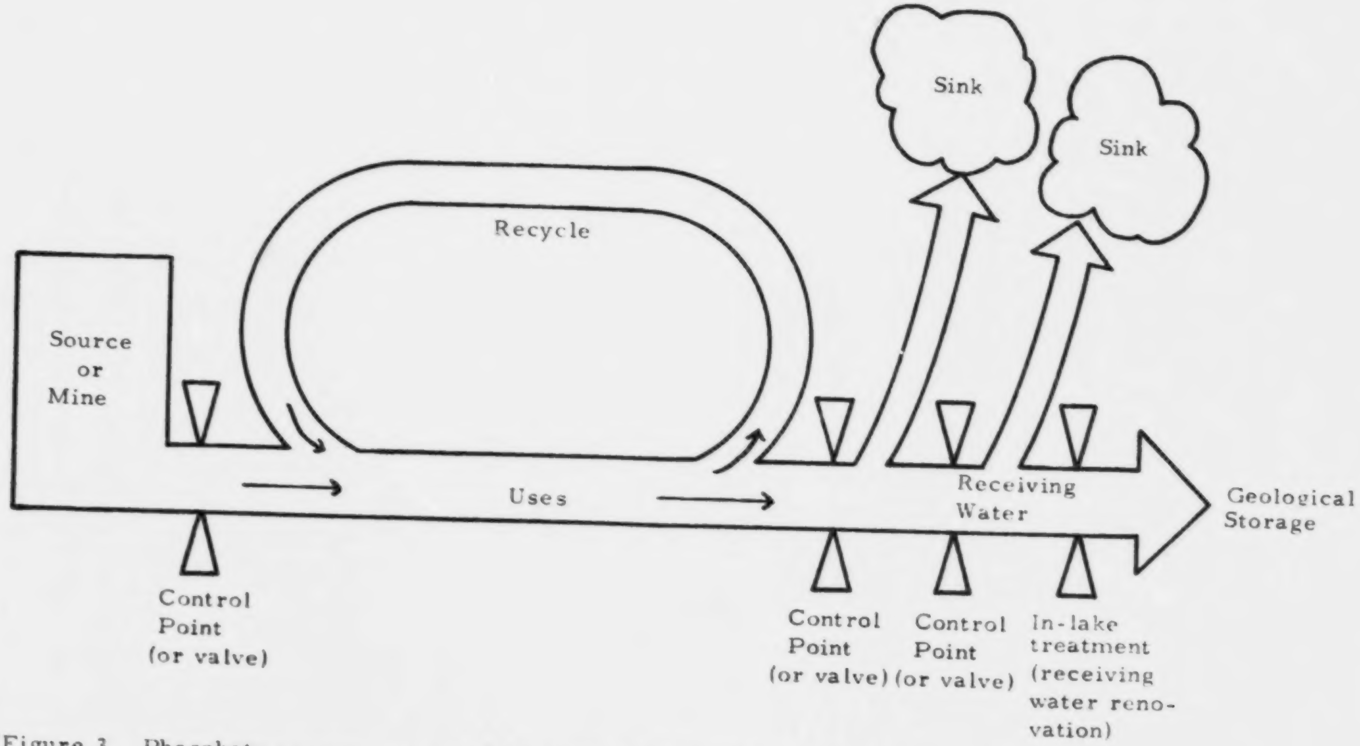

Source or Mine
Recycle
Uses
Sink
Sink
Receiving Water
Geological Storage
Control Point (or valve)
Control Point (or valve)
Control Point (or valve)
In-lake treatment (receiving water renovation)

Figure 3. Phosphate source, use, and final destination with possible points of control.

allowed the development of the activity analysis and the series of control strategies described below. These strategies were then manipulated to reduce the level of phosphorus in surface water and thus reduce eutrophication levels. At the same time the costs of such strategies and their implementation were estimated.

Because of the rather wide variation in the social structure, economic development, hydrologic relationships, and population distribution in the United States, it was decided that the system descriptions would be general enough so that regional strategies could easily be developed, i. e., strategies which would be specific for that particular region. The realization that environmental management requires a regional or perhaps even a basin-wide or subbasin level of coordination and implementation has been developing throughout the Environmental Protection Agency and seems implicit in the new 1972 Amendments to the Federal Water Pollution Control Act (P. L. 92-500). Such a regional capability of strategy implementation becomes a necessity not only from the point of view of practical technology, but from the point of view of implementation.

SECTION IV
EUTROPHICATION

THE PROBLEM OF EUTROPHICATION

Definitions

Eutrophication is the enrichment of surface waters with plant nutrients; oligotrophic (nutrient poor) lakes become eutrophic (nutrient rich) as nutrient concentrations in the lake waters increase. Increased levels of plant nutrients lead to increased plant productivity. The problem of eutrophication results entirely from increased productivity and its consequences caused by the fertilization of lakes, i.e., increasing nutrient concentrations in the lake waters. Nutrient levels increase or decrease naturally in lakes depending on the lake's age and on the geology and past history of a lake basin, but human activities in the basin frequently accelerate nutrient addition and result in what is called "cultural eutrophication." Generally, lake waters that have many high quality uses are considered desirable by human society; these lakes coincide with low-nutrient lakes because the water is less turbid, more aesthetically pleasing, and supports a desirable food chain. Cultural eutrophication decreases these high quality uses. (Detailed descriptions of eutrophication and its effects can be found in Bartsch, 1972;

Hutchinson, 1973; National Academy of Science, 1969; Stewart and Rohlich, 1967; and Vollenweider, 1968.)

Naturally eutrophic lakes occur when the drainage basin provides waters which are high in phosphorus and other nutrients, when sedimentation fills in the lake until it is shallow enough for the lake sediments to participate directly in supplying nutrients to the lake nutrient budget, or when productivity over a period of many years causes the buildup of rich organic sediments so that rapid recycling of nutrients can occur. However, without human influence many lakes will remain oligotrophic for long periods of time. For example, Lake Tahoe--a lake on the order of 2 million years old--is still oligotrophic because of its great depth and the paucity of nutrients in its drainage basin; it is only along the shoreline areas where the activities of man have resulted in higher nutrient concentrations that significant increased productivity is being observed (Goldman and Armstrong, 1969; McGauhey et al., 1971). As another example, hydrographic changes due to human activities have apparently coincided with periods of eutrophication in Lago di Monterosi (Hutchinson, 1969).

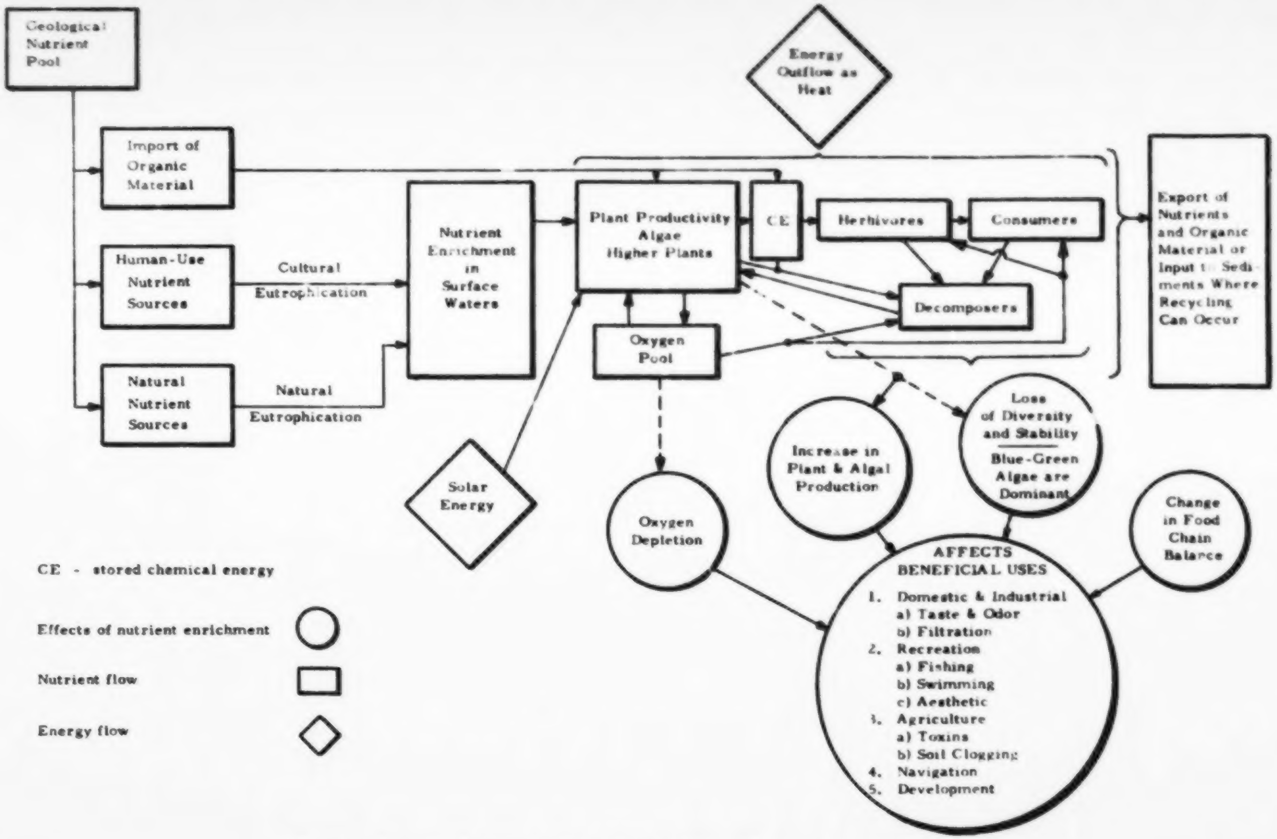
Effects of Nutrients

Increased concentrations of plant nutrients fertilize the lake leading to increased plant productivity. Eventually this increased productivity results in a decrease in dissolved oxygen concentrations and severe interferences with the typical food web relationships and with the balance between different trophic levels in the food web. The geological nutrient pool is the ultimate source of all nutrients for a given lake

(Figure 4). Through human activities and natural occurrences in the lake basin, these nutrients enter a body of water, and through biological reactions driven by solar energy (photosynthesis), are fixed and utilized in the food chain. As nutrient concentrations increase, more plant growth occurs until the following consequences are observed: 1) Dissolved oxygen concentrations exhibit diurnal cycles of supersaturation and deficit and the lake bottom becomes deficient in oxygen; 2) loss of community diversity and stability occurs as blue-green algae become more competitive and occasionally occur as near unialgal dominants in certain lakes (Horne and Goldman, 1972); 3) blue-green algal blooms cause problems of taste and odor and increased filtration problems in domestic water supplies; 4) physical and chemical factors (e.g., causing skin rashes) interfere with recreational and aesthetic uses and thus further recreational development; 5) fish populations change from game fish to rough fish, largely due to low dissolved oxygen concentrations, but also due to changes in food sources; and 6) aquatic weed production interferes with navigation, recreation, and other uses.

Factors Limiting Plant Growth

The logic of controlling phosphorus concentrations (or for that matter, any nutrient) in natural waters so that they limit plant growth and thus control plant productivity, is based on a functional relationship between plant productivity and nutrient concentration. The concept of a limiting growth factor has been developed from "Liebig's Law of the Minimum" (Hutchinson, 1973; Odum, 1959) which can be stated that growth of plants will be controlled by the growth of energy factor in shortest supply.


Geological Nutrient Pool
Import of Organic Material
Human-Use Nutrient Sources
Natural Nutrient Sources
Cultural Eutrophication
Natural Eutrophication
Nutrient Enrichment in Surface Waters
Energy Outflow as Heat
Plant Productivity Algae Higher Plants
CE
Herbivores
Consumers
Decomposers
Oxygen Pool
Solar Energy
Export of Nutrients and Organic Material or Input to Sediments Where Recycling Can Occur
Oxygen Depletion
Increase in Plant & Algal Production
Loss of Diversity and Stability
Blue-Green Algae are Dominant
Change in Food Chain Balance
AFFECTS BENEFICIAL USES
1. Domestic & Industrial
a) Taste & Odor
b) Filtration
2. Recreation
a) Fishing
b) Swimming
c) Aesthetic
3. Agriculture
a) Toxins
b) Soil Clogging
4. Navigation
5. Development
CE - stored chemical energy
Effects of nutrient enrichment
Nutrient flow
Energy flow

igure 4. Diagram of aquatic system nutrient and energy flow.

Many factors are important in controlling levels of plant biomass in aquatic ecosystems (light, temperature, mixing, grazing, CO_2, nutrients), but only certain factors appear to be controllable by man as a practical and economical method of decreasing plant productivity. These are the intrinsic factors of an aquatic ecosystem; macrochemistry of the water, toxicant levels, concentrations and types of organisms present, and the nutrients themselves, nitrogen, phosphorus, iron, manganese, molybdenum, and other trace elements and chelating agents (Porcella, 1969).

Although estimates have been made that a wide variety of nutrients can become limiting to algal communities (e.g., Goldman, 1965), it is probably only the geochemically rare (in relation to algal growth and plant growth requirements) macronutrients, nitrogen and phosphorus, which control the development of the aquatic blooms (Goldman, 1965; Hasler, 1947; Hutchinson, 1957, 1973; Sawyer, 1947). Nitrogen is an essential component of proteins, nucleic acids, and other biologically important macromolecules. The chief sources of nitrogen to algae are the major inorganic forms (mineral nitrogen), nitrate, nitrite, and ammonia. Fixation of atmospheric nitrogen by blue-green algae and by bacteria and bacterial degradation of organic nitrogen to release ammonia can also serve as important nitrogen sources in the aquatic ecosystem.

Generally, phosphorus is available to algae only as orthophosphate. Phosphorus is often stored in cells as polyphosphates and is utilized primarily in nucleic acids, nucleotides, and phospholipids. Cycling of phosphorus from sediments, degradation of organic phosphates, and the hydrolysis of polyphosphates to orthophosphates may serve as a phosphorus source to algae, but the primary though not always the most immediately important of phosphorus sources are in the waters influent to a lake.

The observed effects of high nutrient levels (productivity increase, oxygen deficit, food web changes) have served to define the levels of nitrogen and phosphorus which constitute eutrophication in a lake. Sawyer (1947) has suggested that above a threshold of 0.01 mg P/l and 0.3 mg N/l as a mean winter concentration, eutrophication would exist. Vollenweider (1968) utilized Sawyer's estimates and estimated the following values in terms of annual loadings:

$$P, 0.2 - 0.5 \text{ g/m}^2 \text{ yr., and } N, 5 - 10 \text{ g/m}^2 \text{ yr.}$$

When more than sufficient nutrients are present in a lake to cause eutrophic conditions (e.g., exceeding Sawyer's concentrations), plant growth probably becomes limited by extrinsic factors rather than by nutrients. Light and temperature are the major nonnutrient seasonal factors which limit productivity. Light can also limit overall productivity when turbidity occurs due to significant concentrations of algae and other suspended matter and color. Temperature has important effects on growth rate as well as placing upper limits on survival of specific algae species (Eppley, 1971; Goldman et al., 1972; Reynolds et al., 1973). Because both atmospheric CO_2 and dissolved carbonate species can adequately supply the carbon necessary for algal growth under the most eutrophic conditions likely to be encountered naturally (Schindler, 1971; Goldman et al., 1972), carbon is included with light and temperature as being extrinsic variables which in a practical sense are not easily controlled (Porcella, 1969).

PHOSPHORUS AS A LIMITING FACTOR

Algal Growth and Phosphorus

Assuming that phosphorus limits growth, i.e., if the factor is at a minimum in relation to all other needed factors, certain relationships between algal growth rate and standing crop can be defined. A theoretical and experimentally defined relationship (Monod, 1949) shows that as the nutrient concentration increases the algal growth rate of a unialgal culture increases linearly but that eventually the growth rate approaches a constant maximum value (Figure 5). This first-order zero-order relationship (linear-constant) for growth rate apparently results from the kinetics of uptake of nitrogen and phosphorus (e.g., Eppley et al., 1969; Ketchum, 1939). A similar type of relationship can be developed between the maximum standing crop of algae and the limiting nutrient concentration (Figure 6). The standing crop-nutrient concentration or yield relationship occurs because other factors become limiting as the concentration of a particular limiting factor increases.

These results imply that in lakes a linear relationship between productivity and nutrient concentration occurs only when the limiting nutrient is well below the "saturation level." Thus, if one wishes to decrease algal productivity by decreasing phosphorus concentrations, levels of phosphorus must be attained where algal productivity is proportional to, or limited by, phosphorus concentrations.

Ordinarily, as all the growth factors increase in intensity in nature, the final limitation of growth will be either the innate ability of the

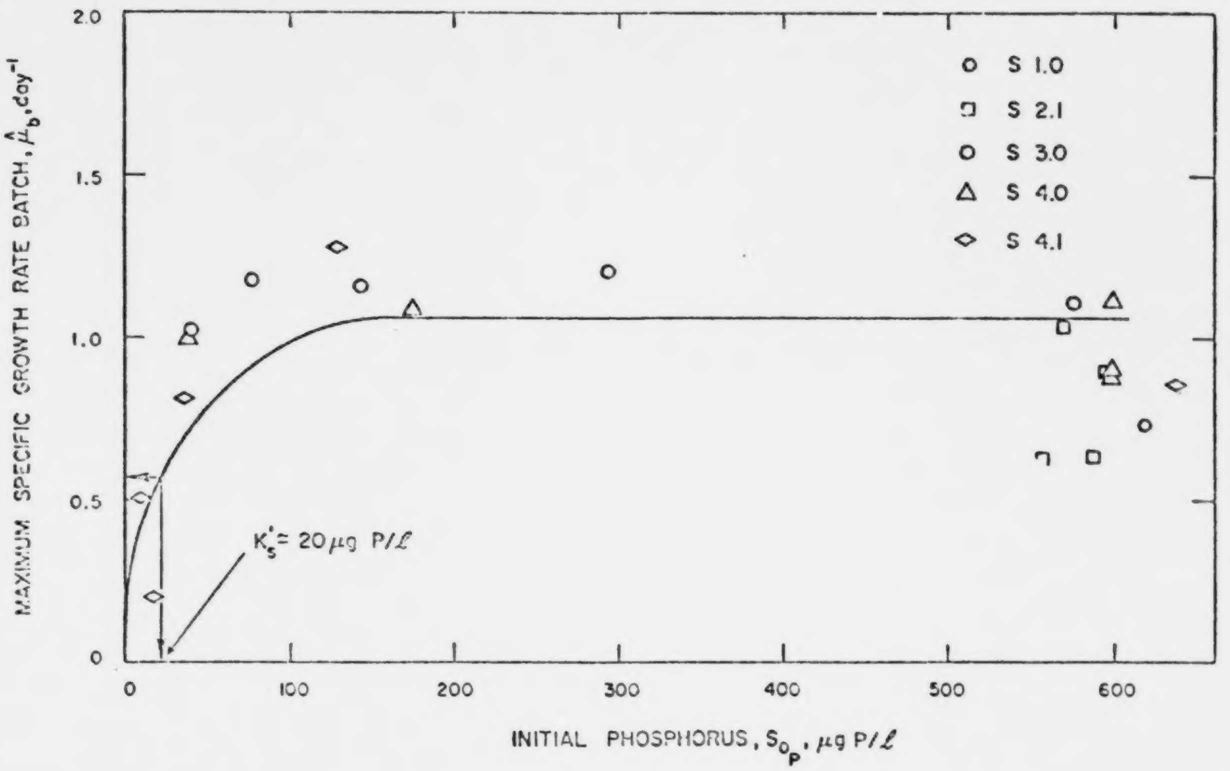


Figure 5. Maximum specific growth rate batch (μ_b) of Selenastrum capricornutum and the relation to initial phosphorus concentration (S_o) in PAAP medium (μ_b calculated from absorbance measurements). Figure taken from Porcella et al. (1970).

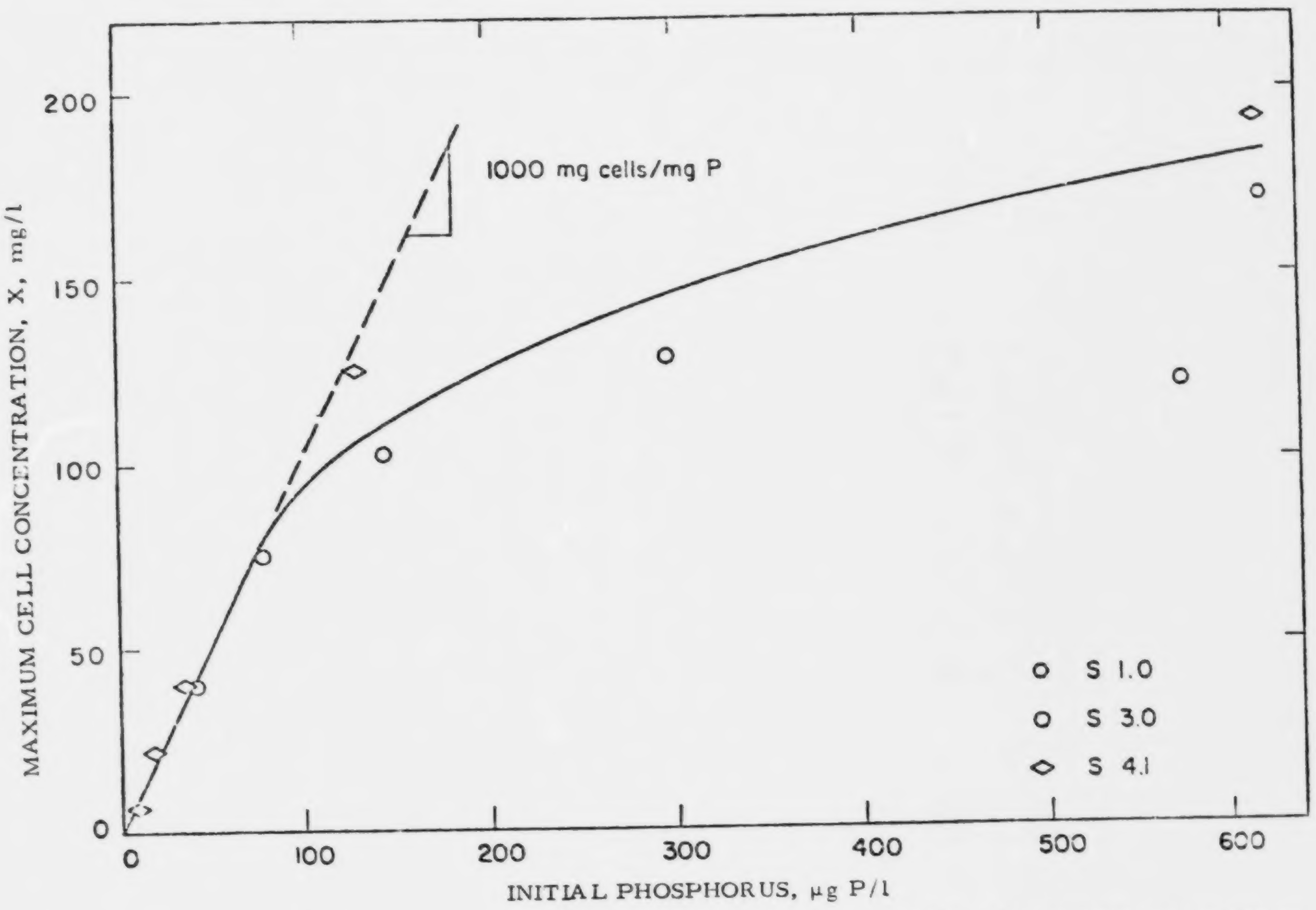


Figure 6. Relationship between maximum cell concentration (X, mg SS/l) and the initial concentration of phosphorus (S_o). Figure taken from Porcella et al. (1970).

organisms to growth, or limitation by some extrinsic factor such as carbon, light or temperature (Goldman et al., 1972; Jitts et al., 1964; Thomas, 1966). From the point of view of controlling phosphorus and thereby productivity, it is necessary to make phosphorus limiting in relationship to all other intrinsic and extrinsic factors.

Methods of Determining the Limiting Nutrient

Methods of determining limiting factors in a particular body of water include: 1) The analysis of nutrient concentrations in the water; 2) bioassays performed either in the lake in enclosures, or in bottles placed in the lake or laboratory with and without the addition (or 'spiking') of nutrients; and 3) comprehensive limnological analysis of the lake. The most accurate method is a comprehensive limnological analysis, but it is expensive and time consuming and cannot be performed routinely. The use of chemical analysis and the development of standard algal bioassay techniques (Provisional Algal Assay Procedures, 1969; Environmental Protection Agency, 1971) provides a more rapid and less expensive method, though not as rigorous a method, for analyzing the trophic state of the water and for determining the limiting nutrient, especially if spiking techniques are used.

Analyses of nutrient content of both water and algae have provided (1) threshold estimates of nitrogen and phosphorus concentrations that limit algal growth (Sawyer, 1947); and (2) ratios of N:P in waters that tend to indicate when one or another of these elements is growth limiting; thus, when the N:P weight ratio in the water is $<$ 15:1, nitrogen is likely limiting, and when the N:P ratio is $>$ 15:1, phosphorus is the possible limiting nutrient (Environmental Protection Agency, 1971;

McGauhey et al., 1969; Schindler, 1971; Vollenweider, 1968). Within the N:P range of ratios of 10:1 to 20:1, multiple limitiations are indicated (Ketchum, 1939; Middlebrooks et al., 1971; Porcella et al., 1970). The N:P ratio of 15:1 merely allows an approximation to determine the growth limiting factor.

Whenever the available form of a nutrient in a water is essentially undetectable, it is possible that it is limiting to algae. Thus, relationships between concentrations of nitrogen and phosphorus have been used to indicate which of these two nutrients are limiting. From Figure 7 it can be seen that considerable nitrogen remains in solution in these lake waters while phosphate concentrations approach zero. Thus, one might conclude that for these two nutrients under these conditions phosphorus is limiting.

The estimation of limiting factors in lakes and water samples by analyzing dissolved nutrients has occupied considerable effort and in some cases has led to some confusion (see discussion in Likens, 1972 and in O'Brien, 1972). This has occurred especially when the role of other factors were not considered, such as light limitation caused by suspended inorganic sediments and other particulate matter. For example, in Clear Lake, California, the algal community is light limited in the springtime because of the high turbidity of the spring runoff and apparently becomes nitrogen limited later in the growing season when the lake becomes less turbid. In this case nitrogen limitation leads to considerable nitrogen fixation by blue-green algae, amounting to about 40 percent of the total nitrogen budget (Horne and Goldman, 1972).

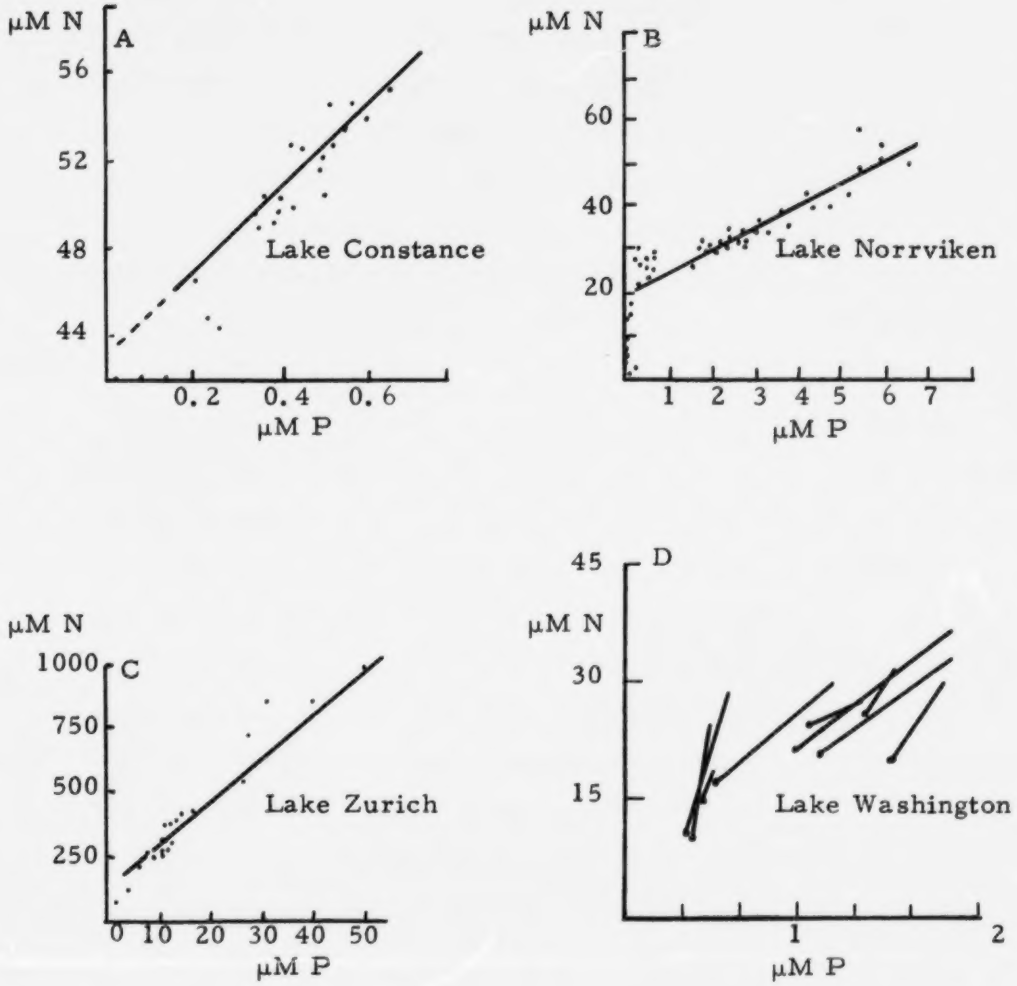


Figure 7. Correlation between concentrations of soluble nitrate and phosphate in eutrophic lakes (A, B, C, from Stumm and Leckie (1970); D from Edmundson (1972)). Data in A, B, C are from various depths and times. The dots in D show the mean particulate N and P in the top 10 m during July and August and the end of the lines attached to the dots shows the dissolved nitrate-N and phosphate-P in the previous winter (January to March) in the top 10 m. Dates in D show the year of analysis and thus reflect concentration changes as a result of nutrient input management.

Further confusion occurs because of problems with sampling in time and space and the interpretation of those results. For example, low concentrations of specific nutrients, or specific forms of a nutrient, are often observed during a bloom leading to the conclusion that a particular nutrient is limiting (e.g., see Doyle, 1971; Ferguson, 1968; and Kuentzel, 1969). As has been shown in natural systems where winter measurements are correlated with bloom conditions (see Edmundson, 1972; Sawyer, 1947), and in bioassays conducted on physical eutrophication test models (McGauhey et al., 1969) the measured nutrients after the bloom only indicate what the algal bloom has left in solution. In such cases if the solution nutrient is close to zero, the nutrient could be limiting; but the nutrient is not necessarily limiting because intracellular storage ("luxury uptake") can cause essentially complete removal of certain nutrients particularly phosphorus (Overbeck, 1962b; Porcella et al., 1970; Toerien et al., 1971). If significant quantities of the nutrient remain in solution, then that nutrient is not limiting. The converse argument that "if a nutrient remains in solution in significant quantities during a bloom then it is not limiting" can be used with greater confidence to show that the nutrient is not growth limiting. These conclusions are indeed the maximum reliable information that can be derived from nutrient levels in solution with regard to whether or not a particular nutrient is growth limiting.

In terms of spatial orientation, comprehensive sampling is often necessary (e.g., see "synoptic sampling" in Horne and Goldman, 1972). This is because the growth of different kinds of algae in the same lake apparently can be limited by different nutrients. Fitzgerald (1969) used direct analysis of cells from algal blooms dominated by a single algal species and showed nitrogen limited and phosphorus limited algae at the same time in Lake Mendota. Thus, in using such a technique, different limiting factors could be demonstrated for a particular lake if there were insufficient regard for differing algal physiology.

Bioassays

Bioassays are useful for determining trophic state and nutrient limitation because they integrate the effects of all intrinsic factors. Such tests have been performed in the laboratory using sealed bottles or open flasks as well as in the field using closed bottles and polyethylene bags. These tests allow an estimation of the trophic state of the lake by comparing the algal growth in the lake with that obtained in the test. One method of estimating trophic state is based on growth rates (Figure 5): Low growth rates and intermediate growth rates indicate that the waters are oligotrophic and mesotrophic respectively (assuming no toxic substances in the sample). High or maximum growth rates indicate that the waters are eutrophic, i.e., nutrients are not growth rate limiting.

In addition, toxicity can be estimated using dilution techniques and the specific limiting nutrient may be estimated by spiking with one or more nutrients and observing the response of the algae. Relative toxicity and biostimulation have been demonstrated for varying treatments of wastewater (Middlebrooks et al., 1971) while several investigations of limiting nutrients for different algae and different waters have been conducted using spiking techniques (e.g., Gerloff, 1969; Maloney et al., 1972).

Schindler studied a lake where nitrates and phosphates were added to make it eutrophic (in analogy to bottle tests where spiking occurs) and found that the lake became growth rate limited by the rate of CO_2 diffusion into the lake. However, it was the added phosphorus that controlled the development of the algal bloom itself and the lake waters became eutrophic because of the additions of nutrients (Schindler, 1971; Schindler et al., 1971; Schindler, 1972).

Similarly, Goldman and Carter (1967) determined that nitrogen was the probable limiting factor in Lake Tahoe waters by spiking large plastic bag in situ enclosures of lake water with specific nutrients.

Another way of determining the relative importance of the various nutrients as growth limiting factors is to examine the typical stoichiometries and growth yields of various algae. Some suggested stoichiometric algal formulae are $C_{106}H_{263}O_{110}N_{16}P_1$ (Stumm and Leckie, 1970), $C_{106}H_{181}O_{45}N_{16}P_1$ (McCarty, 1971), and $C_{520}N_{54}P_1$ to $C_{98}N_{6.6}P_1$ (depending on whether phosphorus or nitrogen respectively were limiting, Porcella et al., 1970). These formulae demonstrate that phosphorus is the lowest constituent of those reported and therefore one might reason that it must be reduced to the lowest concentration relative to the other nutrients to cause it to become growth limiting. By comparing directly the tissue concentrations of important nutrients in plants to these ratios one can estimate whether a particular nutrient may be limiting. Gerloff (1969) has done this for aquatic plants in a very detailed way while Fitzgerald (1969) has indicated that more sophisticated analyses of plants and algae can indicate which nutrients are limiting.

NUTRIENT CONTROL AND EUTROPHICATION

Limiting Factors and Control Methods of Algal Blooms

Considerable effort has been expended on estimating the seriousness of eutrophication as a worldwide problem as well as a U.S. problem. Federal Government estimates of eutrophic waters amount to 25 - 40 percent of U.S. surface waters (House Committee on Government Operations, 1970). Okun (1972) has estimated that 15 percent of the population contributes to eutrophication of inland surface waters. In the Great Lakes Basin where a significant percentage of the North American fresh water supply and population is located, eutrophication is already a severe problem in Lake Erie (FWQA, 1968), a developing problem in Lake Ontario and Lake Michigan, and a potential problem in Lakes Superior and Huron (Table 1). These lakes are apparently phosphorus limited under natural conditions as are most of the Canadian Shield lakes (Schelske and Stoermer, 1972; Schindler et al., 1971).

A selection of North American waters where limiting factors have been described shows that although many factors may be involved, ultimately nitrogen and phosphorus are the most likely limiting factors for algal growth (Table 1). Although the more productive marine waters tend to be nitrogen limited, freshwater environments exhibit a variety of probable limiting factors. It is imperative to remember that lakes are homogeneous in neither time nor space and that Table 1 presents only a selection of estimates; however, for a particular time and place these results represent a considerable body of information and can be useful

Table 1. SELECTED WATER SYSTEMS IN NORTH AMERICA IN RELATION TO AN ESTIMATION OF THE LIMITING NUTRIENT[a]

Lake	Trophic State	Estimated Limiting Nutrient	References
Clear Lake, Calif.	Eutrophic	Light (turbidity), then nitrogen	Horne and Goldman (1972)
Lake Tahoe, Calif.	Oligotrophic	Nitrogen	Goldman and Carter (1965) McGauhey et al. (1969)
Lake Washington, Wash.	Eutrophic	Phosphorus	Edmundson (1972)
Lake 227, Canada	Eutrophic (due to added nutrients)	Phosphorus	Schindler et al. (1971)
Lake Mennetonka, Minn.	Mesotrophic?	Phosphorus	Megard (1972)
Lake Michigan (Great Lakes)	Mesotrophic	Phosphorus	Schelske and Stoermer (1972)
Lake Sebasticook, Maine	Eutrophic	Extrinsic Factors?	Mackenthun et al. (1968)
San Joaquin Delta, Calif.	Eutrophic	Light & Nitrogen	DiToro et al. (1971) Brown et al. (1969)
Marine Coastal Waters Receiving Sewage Effluents			
Atlantic Shore	Productive	Nitrogen	Ryther and Dunstan (1971)
Pacific Shore	Productive	Nitrogen	Eppley et al. (1971)

[a] For references on studies of a large number of lakes, see Frey (1966), Lee (1970), Maloney et al. (1972), Milway (1970), Rawson (1960), Shannon and Brezonik (1972), and Vollenweider (1968).

in extrapolating the effects of different nutrient control schemes on a variety of lake environments.

Once a limiting nutrient has been defined, it is necessary to interpret that result in terms of practical control measures for eutrophication. Some common control methods are only of a temporary nature, attacking the symptoms and effects of eutrophication; other methods are directed at nutrient removal (the causative agent for algal blooms) or to changing the conditions within the body of water to minimize the effects of algal blooms (see Table 2).

By removal to a limiting level of a single factor necessary for plant growth, a reduction in plant productivity will occur. Consequently, efforts towards nutrient removal for effluents have been directed primarily toward the intrinsic factors and chiefly towards phosphorus removal. Agreements between Great Lakes States and the Federal Water Pollution Control Administration (now Environmental Protection Agency) require 80 percent phosphorus removal and new agreements may lead to an effluent standard of less than 1 mg P/l (Lee, 1972). The relative geochemical rarity, ease of chemical removal from wastes, and the lack of an atmospheric source of supply as for carbon and nitrogen have led to the development of technology for phosphorus removal in waste effluents, in spite of the fact that phosphorus is least required in relation to carbon and nitrogen. In addition, there is an extra advantage to phosphorus removal from lakes where phosphorus is limiting because one would expect an immediate response by a lowering of the algal productivity.

Table 2. METHODS OF CONTROLLING EUTROPHICATION AND ITS EFFECTS[a]

	References Citing Specific Examples
Temporary Control Measures	
Harvesting of weeds and/or algae	See Brezonik and Lee (1968) Young and Crossman (1970)
Biological	
Grazing organisms (fish, manatees)	
Blue-green algae viruses	See Prowse (1969)
Chemical	
Copper sulfate	
Organic herbicides	See Fitzgerald (1971)
Permanent Control Measures	
Watershed management	See Likens (1972)
Diversion of nutrient-containing wastes	See Table 3
Nutrient removal from wastes	See Rohlich and Uttormark (1972) for review
Nutrient precipitation in lakes	See Jernelov (1970)
Dilution of nutrients in lakes	See Oglesby (1969)
Deletion of certain specific chemicals from chemical products (polyphosphates in detergents)	See Congressional Hearings (1969)
Lake Modification (see Born, 1972)	
Deepening of lake	
Aeration	See Fast (1971)
Removal of bottom sediments	

[a] Many of these techniques have been discussed in more detail previously (National Academy of Sciences, 1969; Milway, 1970).

Because of the problem of sediment storage of phosphorus and later release to the overlying waters when phosphates in the water become limiting (e.g., Porcella et al., 1970), it has not been satisfactorily demonstrated that a reduction in phosphorus concentration alone in a lake will cause an immediate reduction in algal blooms. The studies by Edmundson (1972) on Lake Washington in Seattle and Sonzogni and Lee (1972) on the Madison lakes indicate that sediment release is not significant (possibly because the upper layers of sediment become exhausted of available phosphorus rather quickly (Porcella et al., 1970)).

Edmundson's results are not completely clear with respect to the effects of phosphorus removal on productivity in the lake. The peak algal population is correlated with the winter maximum orthophosphate concentration, but this might correlate with other factors because phosphorus was not the only nutrient removed by diversion of sewage effluents from Lake Washington. Hence the input of many factors (such as organic substances, nitrogen, vitamins, growth factors, trace metals, chelating agents, etc., which could contribute significantly to productivity) have been removed as well as phosphorus; though it seems likely that at present phosphorus is the growth limiting factor in Lake Washington (Figure 7), the results of other large-scale eutrophication control schemes have not been as well studied (Table 3), and caution is required in interpreting those measures in terms of phosphorus.

Influent Phosphorus Distribution to Lakes

In assessing the effect of the concentration of phosphorus influent to a system it is important to understand that not all forms of phosphorus

Table 3. IMPROVEMENT IN EUTROPHICATION EFFECTS RESULTING FROM DECREASE IN NUTRIENT INPUT

	Method of Control	Reference
North American Lakes		
Lake Washington, Washington	Diversion	Edmundson, 1972
Indian Creek Reservoir, California	P Removal	Porcella et al., 1972
Lake Monona, Wisconsin	Diversion	Mackenthun et al., 1960
Green Lake, Washington	Dilution	Oglesby, 1969
European Lakes		
French Lakes	Diversion	Laurent et al., 1970
Bavarian Lakes	Diversion	Liebman, 1970

(the so-called "total phosphorus") are immediately available to algae for growth. Generally speaking, dissolved orthophosphate is immediately available; dissolved and particulate organic phosphates require bacterial attack (and dissolution) to release dissolved orthophosphate; inorganic condensed phosphates can be readily hydrolyzed by bacteria to dissolved orthophosphate (Overbeck, 1962a); particulate inorganic phosphates (either precipitated or sorbed to clay minerals) require dissolution, usually by pH decrease, to become readily available to algae as dissolved orthophosphate. Thus a total phosphorus analysis--an analysis that is commonly performed on agricultural drainage waters--does not indicate how much phosphorus is immediately available for algal growth, but it may represent the potentially available phosphorus.

However, the total phosphorus concentration during the summertime algal bloom in eutrophic lakes when most of the phosphorus is in the algal cells appears to be closely related to the winter dissolved orthophosphate concentrations, i.e., the phosphorus which is available for algal growth (Edmundson, 1972). Thus, Vollenweider's (1968) loading rates which are expressed on an annual basis for total phosphorus seem more reasonable. Moreover, he has shown a reasonable correlation between spring total phosphorus concentrations and annual total phosphorus loadings in eutrophic lakes (Figure 8).

Phosphorus entering a lake can be distributed between several phases (Figure 9): The water (epilimnion and hypolimnion), and sediment (and its interstitial water), the biota, and the inorganic particulate material. All of these phases interact and therefore are involved in the natural phosphorus cycle of the lake. Based on the nutrient budget of 11 eutrophic European lakes it has been estimated that an average of about 55 percent of the phosphorus entering the lakes was retained in them, presumably in the sediments (Vollenweider, 1968).

Analyses of waters entering a small eutrophic reservoir in Utah (Hyrum Reservoir) have indicated that of the total phosphorus input, less than 50 percent was dissolved orthophosphate and directly available for algal growth (Porcella et al., 1972b). During algal bloom conditions, orthophosphate became incorporated into algae and other plants and decreased eventually to almost undetectable concentrations in the water. Settling, incorporation into the food chain, and decay tended to remove the majority of the accumulated algal biomass to the sediments although a fraction was removed via outflow. Fifty-four percent of the influent

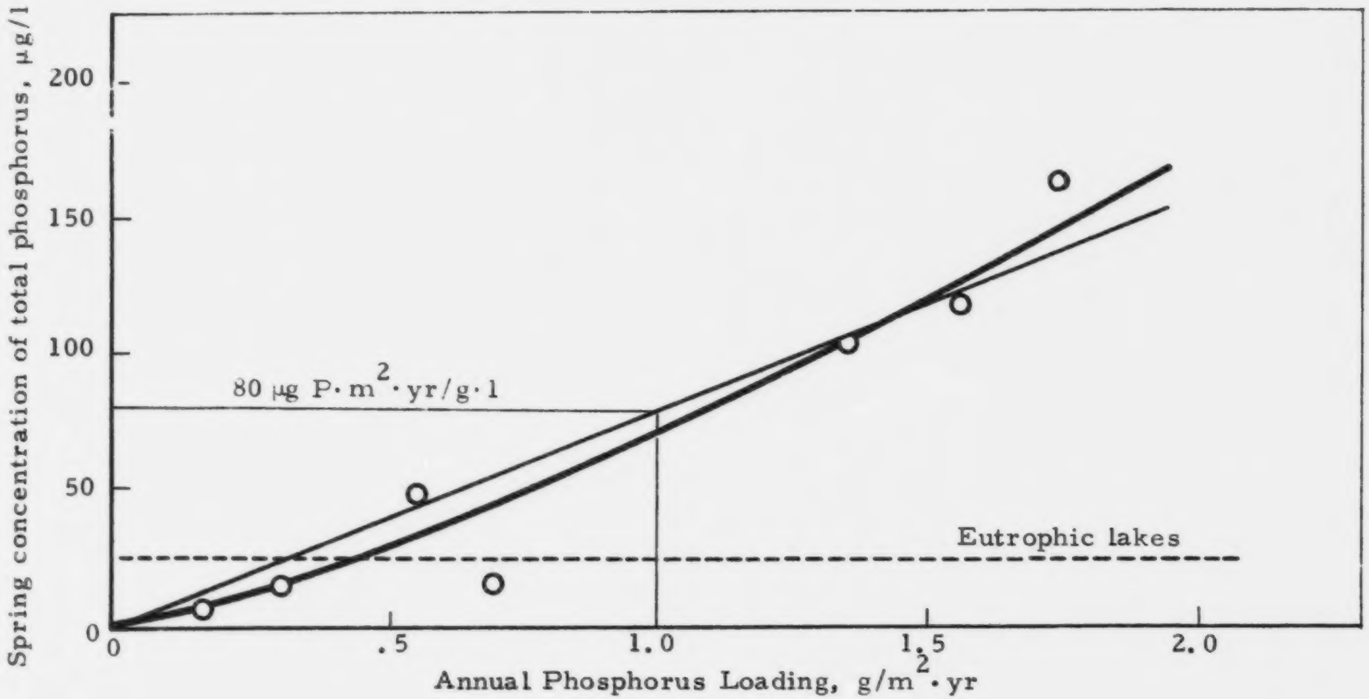


Figure 8. Spring concentrations of total phosphorus apparently are related to total phosphorus loading (from Vollenweider, 1968).

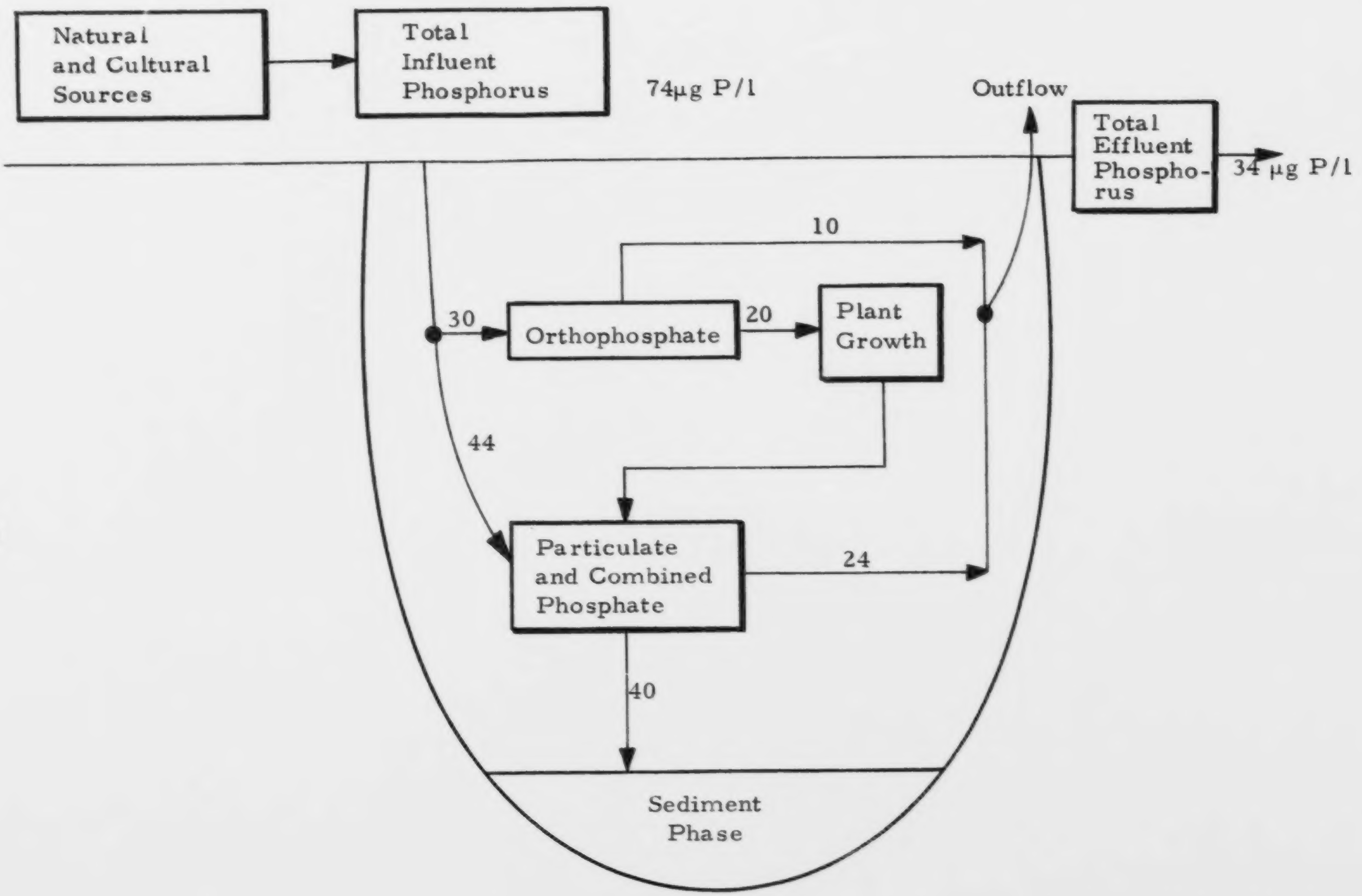

Natural
and Cultural
Sources
Total
Influent
Phosphorus
74μg P/l
Outflow
Total
Effluent
Phospho-
rus
34 μg P/l
10
30
Orthophosphate
20
Plant
Growth
44
Particulate
and Combined
Phosphate
24
40
Sediment
Phase

Figure 9. Average spring-summer phosphorus flow in Hyrum Reservoir, April 4 to November 4, 1971. (Porcella et al., 1972b.)

phosphorus remained in this lake--a figure very close to that of Vollenweider quoted above. However, one should not be misled by this similarity because the percentages of incoming phosphorus retained in eutrophic lakes or reservoirs can be quite variable, from about 89 percent in a new reservoir formed from treated effluent (Porcella et al., 1972a) to nearly zero in a naturally eutrophic lake (Frink, 1967).

These transfers to the sediment sink have been conceptualized in terms of a lake phosphorus residence time independently by Vollenweider (1969) and Megard (1971) and elaborated by Sonzogni and Lee (1972). The relationships expressed in this report were taken from the work of Uttormark (1973). The phosphorus concentration (C) within a completely mixed system is the same as in the outflow and if the inflow concentration (C_i) is partitioned between the aqueous and sediment phases, a hydraulic residence time $(R_H = V/Q$, V is the volume and Q the outflow) and a phosphorus residence time $(R_P = \frac{V}{Q + kV}$, where k represents the fraction partitioned to the sediments) can be defined such that

$$C = C_i \left(\frac{R_P}{R_H}\right) + \left(C_o - \frac{C_i R_P}{R_H}\right) \exp\ (-t/R_P) \qquad (1)$$

and C can be determined for any time (t). Where the system is assumed to be at steady state the ratio of R_P/R_H can be determined from estimates such as in Figure 9, i.e., $C/C_i = R_P/R_H$. For Hyrum Reservoir $R_P/R_H = C/C_i = 0.46$ and since R_H averages about 0.2 years (Porcella et al., 1972b), the mean steady state phosphorus residence time would approximate 0.1 year.

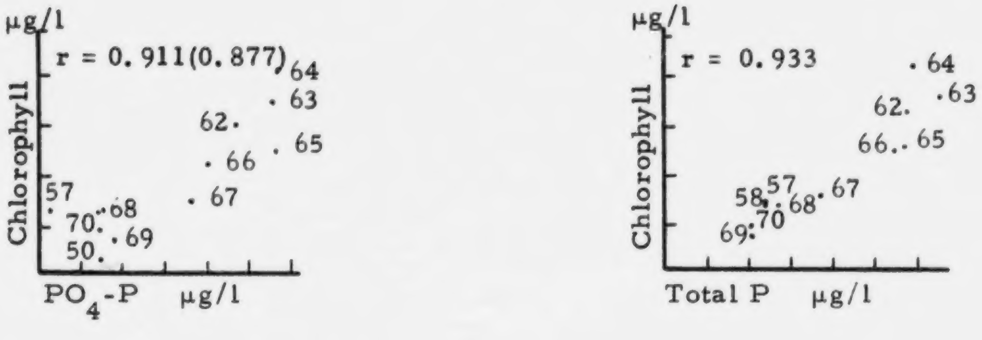
The partition values signify the vast quantity of phosphorus in the sediments (Megard, 1971; Stumm and Leckie, 1970; Vollenweider, 1968). Transfer of phosphorus to the sediments will have an important role in shortening the recovery time needed for a lake where phosphorus input is restricted, especially in comparison to models based only on hydraulic residence time.

Relationship of Algal Growth to Phosphorus Concentration

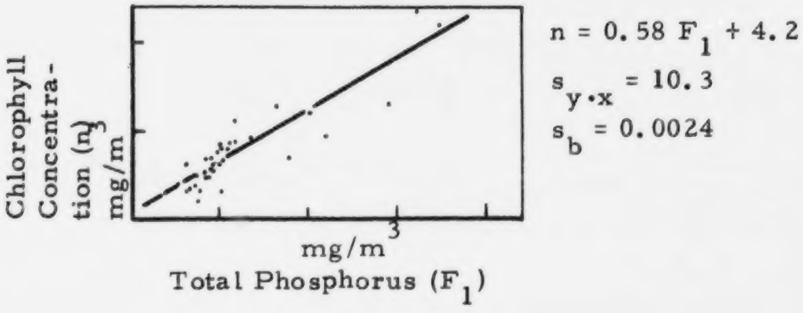
As was shown in Figures 2 and 3, the relationship of phosphorus concentration to algal growth rate and to biomass levels was linear at first but eventually reached a constant maximum value. However, the situation is more complex because of factors such as intracellular phosphorus storage (Overbeck, 1962b) and interrelationships with other growth limiting factors. In spite of these seeming complexities and the problems associated with lake estimations of algal populations, Edmundson has shown straight line relationships

$$\begin{aligned} &\text{Chlorophyll } \underline{a} \ (\mu g/l) = 1.4 \ (PO_4\text{-P}, \mu g/l) + 7.9, \ r = 0.89; \text{ and} \\ &\text{Chlorophyll } \underline{a} \ (\mu g/l) = 0.94 \ (\text{Total P}, \mu g/l) - 4.2, \ r = 0.96, \end{aligned} \tag{2}$$

to exist between phosphorus and chlorophyll concentrations in Lake Washington for the years 1962 to 1970. (Data extrapolated from Figure 10A, see Edmundson, 1972.) From this type of correlation it would appear that phosphorus concentrations have controlled algal growth in Lake Washington, at least within the last decade. Prior to that time other factors apparently limited algal growth. A linear relationship between phosphorus concentration and algal concentration (for example



A. Lake Washington, planimetric means for the top 10 meters of phosphate (January/March) and chlorophyll a and total phosphorus (July and August) (Edmundson, 1972). Correlation coefficients (r) are shown; value in parentheses includes 1957 data point.



B. Lake Minnetonka, surface samples from 11 locations (Megard, 1972)

Figure 10. Chlorophyll a concentration appears related to winter orthophosphate and summer total phosphorus concentrations.

as in Lake Washington) apparently will exist when phosphorus is the only limiting factor. Megard (1972) developed the relationship:

$$\text{Chlorophyll } \underline{a}\ (\mu g/l) = 0.6 \text{ Total P } (\mu g/l) + 4.2 \qquad (3)$$

for the summer populations of algae and the total phosphorus concentration for Lake Minnesota (Figure 10B). The differences between the slopes of the relationships of Megard and Edmundson most probably reflect the differences in the lakes and their algal communities.

Multiple Limiting Factor Model

While relationships such as those of Edmundson (1972) and Megard (1972) are of value in specific situations, for the general situation where factors other than phosphorus could be limiting, a more general model is more applicable than such linear relationships and would include the effects of other limiting factors. Models relating specific growth rate (μ) to limiting factors have been derived for nutrients in lakes (Chen, 1970) and using outdoor laboratory ponds for light and temperature (Middlebrooks and Porcella, 1970). If combined, these relationships would have the general form:

$$\frac{dX}{Xdt} = \mu = \frac{\hat{\mu} S_C}{S_C + K_C} \cdot \frac{S_N}{S_N + K_N} \cdot \frac{S_P}{S_P + K_P} \cdot \frac{l}{l + K_l} \cdot (1.047^{T-20^{\circ}C}) \qquad (4)$$

in which X = mass of cells, ML^{-3}

t = time, t

$\hat{\mu}$ = maximum specific growth rate, t^{-1}

l = light intensity

T = temperature, $^{\circ}C$

all K values are half saturation constants

S_C, S_N, S_P = concentration of available nutrients in the liquid phase (C = carbon, N = nitrogen, P = phosphorus), ML^{-3}.

The relationship between growth rate (μ) and levels of eutrophication is still unclear; however, as noted in the section on bioassays, a lake is generally eutrophic when the measured bioassay growth rates are near maximum and oligotrophic when bioassay growth rates are low. The utility of determining growth rate lies in models which describe population changes in terms of rates, such as growth, settling, predation, hydrodynamics, lake depth and morphology (e.g., Chen, 1970; DiToro et al., 1971; Porcella et al., 1970).

Single Factor Limitation

An alternative and simpler approach to estimating the relationship between limiting factors and algal growth is to use yield factors or stoichiometric formulations as have been previously discussed. The yield (Y) is defined as the mass of algae (X) obtained per unit of limiting nutrient utilized. For a worst possible situation one might assume that all the limiting nutrient will be utilized.

Therefore, for any limiting nutrient

$$X = YS_o \qquad (5)$$

in which S_o is the influent limiting nutrient (phosphorus) concentration.

Essentially, this concept is equivalent to the linear relations of Edmundson (1972) and Megard (1972).

Schindler et al. (1971) have taken another approach which they based on Vollenweider's work (1968). They calculated a log functional relationship for "admissible (A)" and "dangerous (D)" nitrogen and phosphorus levels between nutrient loading ($g/m^2 \cdot yr$) and the mean depth ($\overline{Z}$) of the receiving water:

$$\begin{aligned} \log_{10} P_A &= 0.60 \log_{10} \overline{Z} + 1.40 \\ \log_{10} P_D &= 0.60 \log_{10} \overline{Z} + 1.70 \end{aligned} \tag{6}$$

$$\begin{aligned} \log_{10} N_A &= 0.60 \log_{10} \overline{Z} + 2.57 \\ \log_{10} N_D &= 0.60 \log_{10} \overline{Z} + 2.87 \end{aligned} \tag{7}$$

Oligotrophic lakes are found to occur at loadings below admissible levels while eutrophic lakes occur at loadings above dangerous levels and presumably mesotrophic lakes lie in between the admissible and dangerous loading levels.

Both Vollenweider (1968) and Schindler et al. (1971) have suggested considerable caution in the use of these relationships because of the lack of confirmatory studies and the great error in using such a simple formulation for the description of such a complex and highly variable system. With this warning in mind, further extension of Vollenweider's loading estimate will be made to obtain provisional guidelines to estimate the relation between influent phosphorus and eutrophication.

DEVELOPMENT OF A SIMPLE MODEL FOR RELATING ALGAL GROWTH AND LOSS OF BENEFICIAL USES OF PHOSPHORUS INPUT

For lakes having different fixed mean depths ($\overline{Z}$), Equation 6 gives an estimate of the two points, admissible and dangerous, on the eutrophication-phosphorus relationship (see Figure 11). Thus, an annual phosphorus loading rate can be calculated from the phosphorus input model (see Section VI for description of phosphorus input model, pp. 149-152) and related to the mean depth of a particular lake using the relationships in Figure 11. The effect on phosphorus input by a particular phosphorus management scheme can be related to levels of eutrophication and then evaluated in terms of cause and effect in relation to the cost of the management scheme. Further analysis of relationships between algal growth parameters and loading are contained in Appendix A.

Assumptions Involved in the Eutrophication Model

The foregoing analysis is based on Vollenweider's model (Figure 11) and relies on many assumptions, some of which are too broad, some too inclusive, and some probably incorrect. However, the model shown in Figure 11 represents an attempt to quantify a relationship between eutrophication and phosphorus input so that the effects of certain phosphorus management strategies can be assessed on a specific lake. The model has the advantages of being simple and unsophisticated and requiring the minimum of input data. The following discussion lists

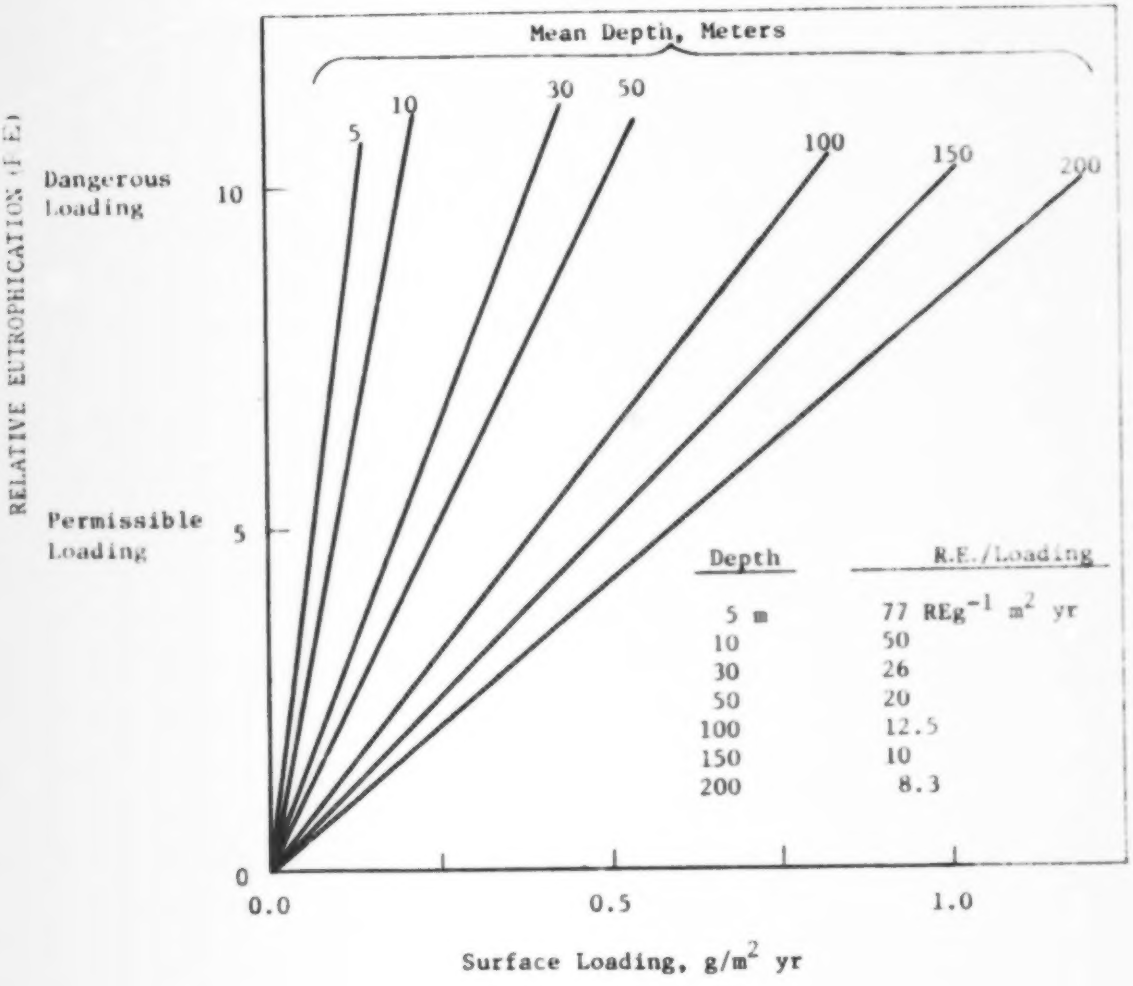


Figure 11. Relative eutrophication in lakes having different mean depths.

the major assumptions made in the model and discusses these assumptions in relation to the project objectives:

1. Only phosphorus limits growth--in the lakes that will be used as examples, the initial assumption is that phosphorus is the limiting nutrient. In the context of the project this is the rationale for minimizing phosphorus input to lakes at least cost (even though in some cases this may do little to alleviate the eutrophication problems in the lake). In the examples lakes will be studied (Lake Erie and Lake Michigan) which are considered phosphorus limited or, at least, where phosphorus can likely be made limiting.
2. The model of phosphorus loading versus eutrophication effects applies to all lakes--such a simple model (Figure 11) only considers one variable in lakes (depth) while lakes vary in other morphological factors in their chemistry, biology, light, temperature, hydrology, geology, etc. Until further analysis of loading-response relationships in a wide variety of lakes is achieved, it seems reasonable to utilize Vollenweider's simple formulation.
3. The number of variables involved can be minimized--this model only considers depth and nutrient loading; formulations exist which contain more variables (e.g., Shannon and Brezonik, 1972). However, these models do not contain more sophisticated cause and effect relationships; the models do require considerably more data without eliminating any significant deficiencies for the purposes of this project.
4. The phosphorus loading factor is based on input of phosphorus which is considered "available" for algal growth rather than

for total phosphorus. Where convenient, relative eutrophication will be shown for available and total phosphorus loading but available phosphorus loading will be the basis for cost calculations. This assumption seems the most reasonable in terms of current knowledge of the natural system but is an assumption which should be checked at the earliest opportunity.

SECTION V

PHOSPHORUS SOURCES TO SURFACE WATERS

OVERALL SUMMARY OF PHOSPHORUS SOURCES

Ultimately all phosphorus comes from minerals. These minerals are weathered by natural processes or utilized by man and other organisms causing the release of phosphorus for recycling through biological communities or for transport to the oceans. After entering a lake or ultimately the ocean, the processes of biological deposition, physical deposition, and chemical precipitation transfer phosphorus to the bottom sediments where it is stored until geologic time restores it to the land surface for further utilization.

Although there are many natural processes which serve as sources of phosphorus to surface water, human activities, at least in the USA, probably account for the majority of phosphorus mass inputs (see Figure 12). Cultural processes cause an increase in phosphorus input to surface waters in comparison to the natural inputs normally expected for a particular system. Natural inputs consist largely of solution effects as water passes over and weathers geological formations. Some phosphorus becomes cycled through biological materials prior to entering water systems as inorganic or organic phosphorus compounds,

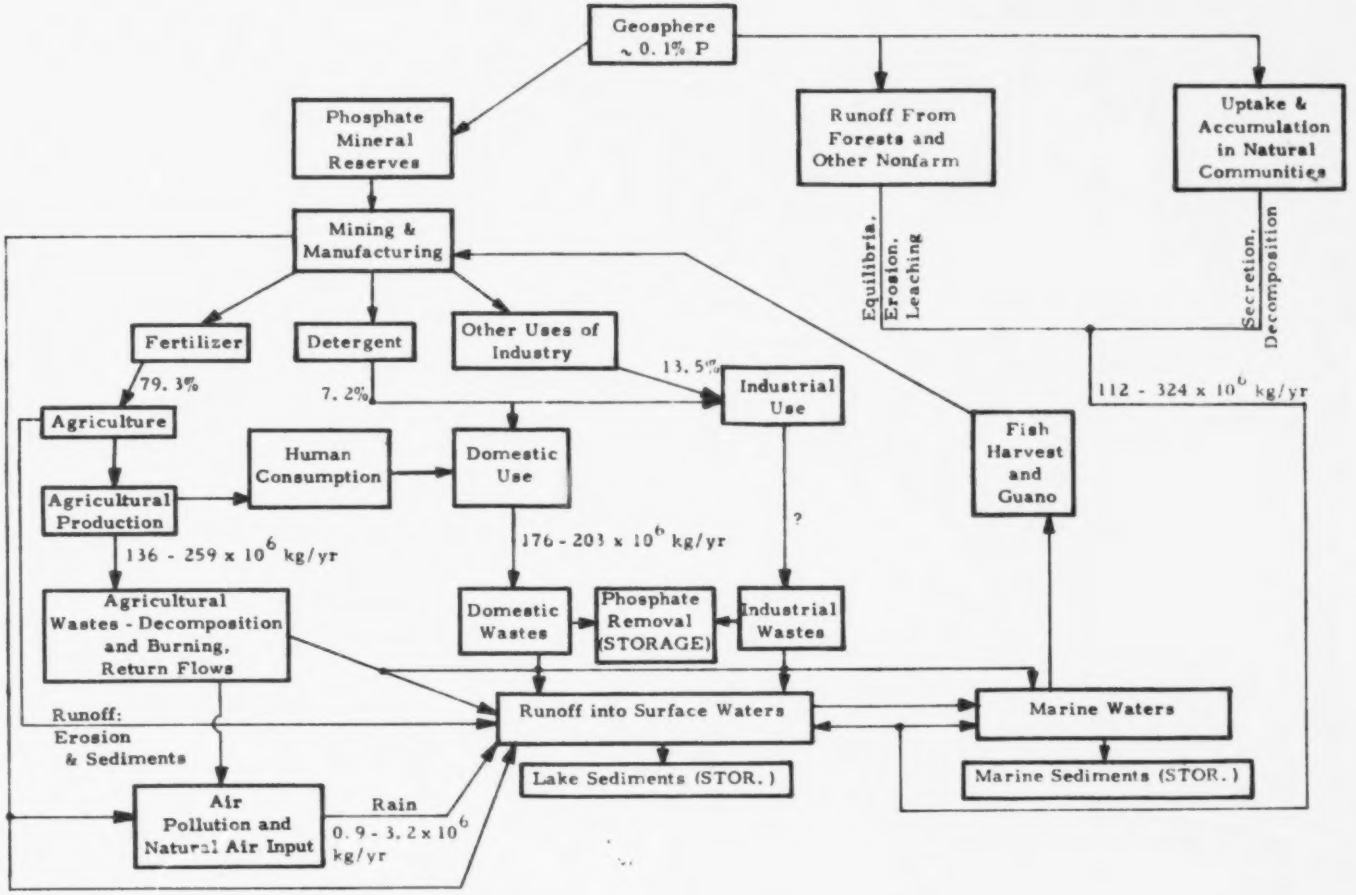

Geosphere
~ 0.1% P
Phosphate Mineral Reserves
Runoff From Forests and Other Nonfarm
Uptake & Accumulation in Natural Communities
Mining & Manufacturing
Equilibria, Erosion, Leaching
Secretion, Decomposition
Fertilizer
Detergent
Other Uses of Industry
79. 3%
7. 2%
13. 5%
Industrial Use
112 - 324 x 10^6 kg/yr
Agriculture
Human Consumption
Domestic Use
Fish Harvest and Guano
Agricultural Production
136 - 259 x 10^6 kg/yr
176 - 203 x 10^6 kg/yr
?
Agricultural Wastes - Decomposition and Burning, Return Flows
Domestic Wastes
Phosphate Removal (STORAGE)
Industrial Wastes
Runoff: Erosion & Sediments
Runoff into Surface Waters
Marine Waters
Lake Sediments (STOR.)
Marine Sediments (STOR.)
Air Pollution and Natural Air Input
Rain
0. 9 - 3. 2 x 10^6 kg/yr

Figure 12. Simplified present-day mass flow diagram for phosphorus in the USA. Data from Ferguson, 1968; The Institute of Ecology, 1971; and Table 4, this report.

but ultimately, these biologically derived compounds come from phosphorus minerals also.

CULTURAL USE OF PHOSPHORUS

Essentially all use of phosphorus by human society depends on the phosphorus mining industry. In 1968, the estimated distribution of phosphorus obtained from mining activities was primarily to agriculture (about 80 percent used in fertilizers and commercial animal feeds), with a considerably smaller amount (7-13 percent) used as phosphate builders in the detergent industry and the remaining 7-13 percent used for various industrial purposes and as product additives (see Table 4).

Future changes in the usages of phosphorus, particular fertilizer and animal feeds, detergent, and industrial uses, will depend primarily on population changes, changes in agricultural practices (chiefly due to urbanization of agricultural lands and international trade policies), possible restrictions on detergent phosphorus uses, and on industrial uses. Technological developments will probably have minimal effect on the use of phosphorus products.

The pathways shown in Figure 12 indicate that most of the activities involved with phosphorus entering surface waters are associated with human activities. The natural sources are quite variable and are dependent on many factors as will become evident in the description that follows. The cultural uses tend to be more constant, but the inputs to surface waters vary with discharge regulations and geography for the diffuse sources.

Table 4. PHOSPHORUS CONSUMPTION IN THE USA

Uses	Amount Used, 100 Kg/yr[a] as P (percent of total)	
	Year: 1958[b]	1968[c] (estimates)
Fertilizers	896 (69.7)	2406 (76.3)
Animal Feed	107 (8.3)	94 (3)
Detergents	171 (13.3)	227 (7.2)
Metal Finishing	15 (1.1)	94 (3)
Other Uses	97 (7.6)	331 (10.5)
Water Softening	35 (2.7)	35 (1.1)
Food and Pharmaceutical	38 (3)	58 (1.8)
Gasoline Additives	8 (0.6)	29 (0.9)
Plasticizers		
Pesticides		
Miscellaneous	16 (1.3)	210 (6.7)
TOTAL	1286 (100)	3153 (100)

[a] To obtain 1000 short tons of P/yr, multiply by 1.1013.

[b] Taken from Logue (1959).

[c] Taken from Lewis (1970).

The flow chart shown in Figure 12 has been combined together with information in Table 4 to develop an activity analysis (Figure 13); i.e., to identify and quantify as precisely as present literature allows all of the natural and cultural activities which tend to produce phosphorus inputs to surface waters. These have been classified into 1) nonbasin activities; 2) agriculture; 3) urban and rural watersheds; 4) domestic; 5) industrial; 6) mining; and 7) animal production.

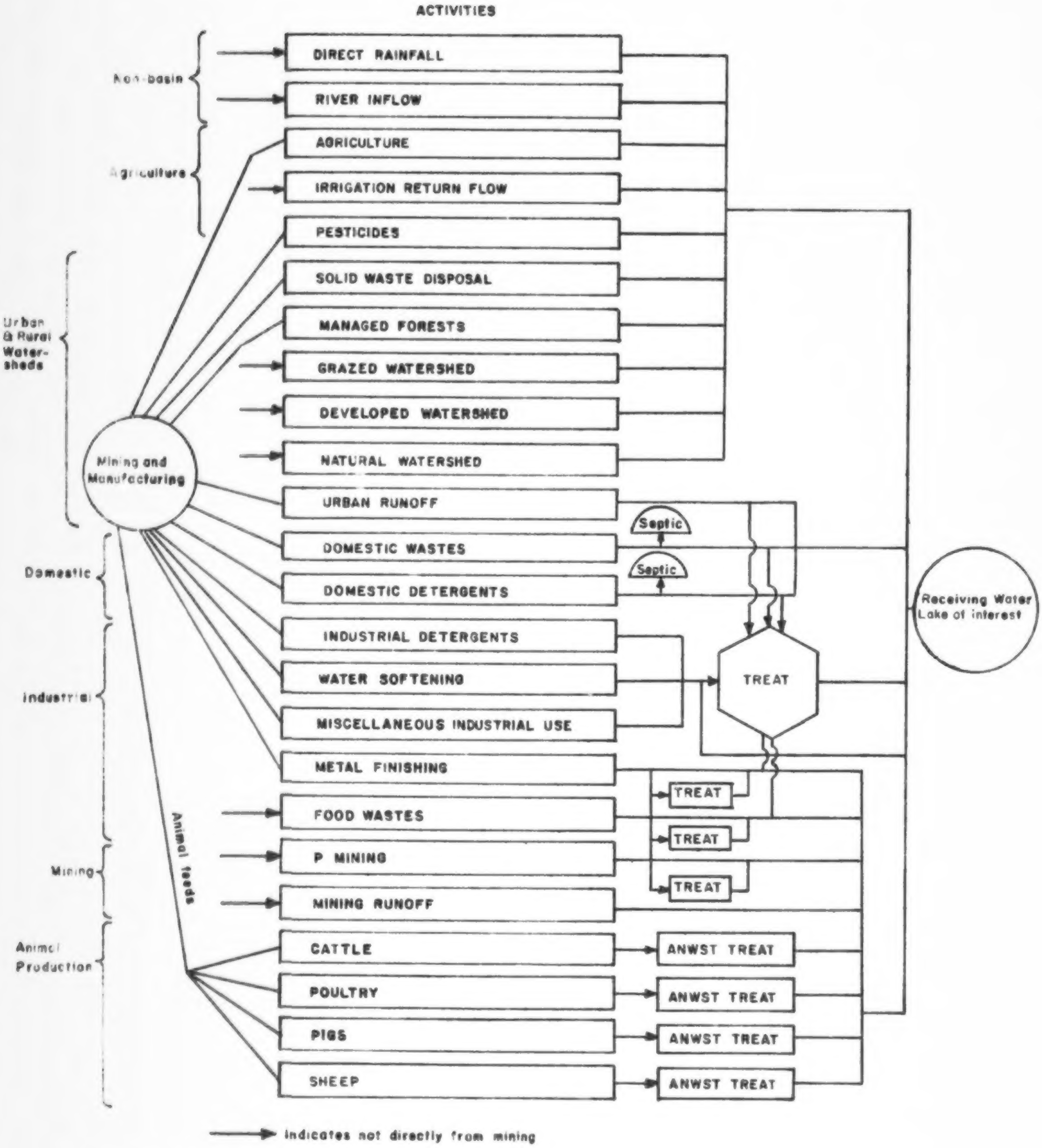

ACTIVITIES
Non-basin
Agriculture
Urban & Rural Watersheds
Domestic
Industrial
Mining
Animal Production
Mining and Manufacturing
Animal feeds
DIRECT RAINFALL
RIVER INFLOW
AGRICULTURE
IRRIGATION RETURN FLOW
PESTICIDES
SOLID WASTE DISPOSAL
MANAGED FORESTS
GRAZED WATERSHED
DEVELOPED WATERSHED
NATURAL WATERSHED
URBAN RUNOFF
DOMESTIC WASTES
DOMESTIC DETERGENTS
INDUSTRIAL DETERGENTS
WATER SOFTENING
MISCELLANEOUS INDUSTRIAL USE
METAL FINISHING
FOOD WASTES
P MINING
MINING RUNOFF
CATTLE
POULTRY
PIGS
SHEEP
Septic
Septic
TREAT
TREAT
TREAT
TREAT
ANWST TREAT
ANWST TREAT
ANWST TREAT
ANWST TREAT
Receiving Water Lake of interest
Indicates not directly from mining

Figure 13. Activity analysis for phosphate indicating the major pathways to any lake for the most typical uses.

NONBASIN ACTIVITIES

These activities are those which are not directly controllable by man or are outside the basin of interest. The first of these includes direct rainfall or precipitation on the water surfaces in the basin. This input has been shown to be a measurable value for Lake Michigan by Lee (1972) and considers the concentration of phosphorus in precipitation. Chapin and Uttormark (1972) have shown that the phosphorus concentration in rainfall is quite variable across the United States. The availability of phosphorus in rainfall to algae is still in question.

The sources of phosphorus in rainfall are probably natural particulate phosphorus which is carried by wind, or other particulate input processes, into the atmosphere and later is removed by rainfall and other precipitation. However, industrial processes, particularly phosphorus mining activities, can lead to rather high concentrations of phosphorus in rainfall (Fuller, 1972). Although such activities can be significant in a particular basin depending on season, prevailing winds and precipitation, they generally represent an uncontrollable source. Another input to the atmosphere which is probably an uncontrollable source is the addition of organic phosphates to gasoline. These phosphates are generally considered to enter the atmosphere and be distributed in that phase. The total quantity of phosphorus used as a gasoline additive is rather small, about 500,000 kg/year, or 0.01 percent of the total USA phosphorus consumption in 1968, and can be ignored. Similar industrial uses of phosphorus could also end up in the atmosphere, but generally are rather small in comparison to the controllable inputs.

In general, one would conclude that the phosphorus content of direct rainfall on water surfaces is not manageable, with the possible exception of phosphorus particles resulting from phosphorus mining operations.

River flow into the basin is a special addition to the system of study, which allows the calculation of phosphorus input via water carriage arising from activities in another basin. An example of this is the inflow into Lake Erie from Lake Huron. If the analysis is being performed only on the Lake Erie basin, one is not able to be concerned with the activities occurring above that basin. Thus, Lake Huron input is calculated separately and independently of the activities in the Lake Erie basin. Any rivers or activities which are specific to the basin or which arise in the basin will be analyzed as part of the overall activities in the basin. Thus, this is the only part of the phosphorus activities basin which takes a typical nutrient budget approach, i.e., the concentration in the river water inflow to the lake of interest times the volume of inflow.

The question of groundwater sources was considered to be an area where (1) little control could be exercised, (2) little information about sources to lakes in terms of water flow or phosphorus concentration was available, (3) previous investigators have largely ignored the effects of groundwater. One of the most careful analyses of the groundwater contribution to the phosphorus nutrient budget was performed recently for two small lakes where groundwater influent would likely be quite important because of septic tanks, the gravelly soil substrate, and relatively high annual rainfalls (Cooke et al., 1973). These investigators found that with the one exception of 20.1 percent obtained during the winter the percent of the phosphorus budget from groundwater varied within the range of 1.8 to 13.1 percent over the various seasonal quarters. The median contribution was 4.4 percent. On an annual basis about 5.3 percent for the West Twin Lake and 2.8 percent for East Twin Lake came from groundwater input. The authors state that groundwater influent phosphorus contributions "...are small and constant." Although for these two lakes groundwater would be expected to contribute considerable phosphorus, Cooke et al. (1973) showed that it was a minor input. Thus, for the three reasons cited above, the groundwater contribution to lakes is not determined for this study and groundwater phosphorus is considered a minor but constant input to the system.

Conversely, it would be expected that lakes could contribute phosphorus to the groundwater pool. Except for coarse textured soils, phosphorus travel through soils is generally very low because of the opportunities for chemical precipitation, sorption, and exchange on calcium carbonate surfaces. Under appropriate conditions (anaerobic, low Eh and pH) transport of phosphorus from lakes to groundwater, soil to groundwater, or groundwater to lake would be maximized. Septic tank drainage, feedlot location, and groundwater recharge would be good examples of how conditions could occur which maximize such transport. In the lakes described by Cooke et al. (1973) septic drainage entered the surface waters. Hence, evidence for such transport mechanisms for phosphorus is not available at this time and so such possibilities for transport will not be considered in this report.

AGRICULTURAL ACTIVITIES (SOIL EROSION, AGRICULTURAL PRACTICES, AND IRRIGATION RETURN FLOWS)

The use of fertilizer and crop harvesting are the most important agricultural practices in terms of the total mass of phosphorus resulting from nonurban human activities.

Phosphorus Pollution of Waters and Fertilizer Use

Agriculture is man's oldest effort to manipulate nature to satisfy his fundamental need for food and fiber. With the advent of planned incentive to increase yields in plant and animal production, it soon became apparent that the more productive a system is, the simpler the system becomes, i.e., a decrease in the diversity and the complexity of the species occurs. Herein lies one of the major problems of environmental pollution, for the simpler an ecological system becomes, the less stable it is with regards to damage from outside sources (Cooper, 1970).

The development of agricultural technology has resulted in a dramatic increase in man's capability to simplify certain ecosystems. These in turn interact with other ecological processes to create chain-like events of major importance beyond the limits of the original ecosystem.

In the quest of increasing agricultural production and its corresponding economic gain, the original, closed biochemical nutrient cycles of a given ecosystem have been altered to the extent where worldwide consequences are now evident.

The efficiency of the fertilizer industry has played a major role in the degradation of the closed nutrient cycle in nature. The economics of commercially available nutrients are such that the application of commercial fertilizers to agricultural lands is essential for a viable enterprise. It is estimated that from 1/3 to 1/2 of all agricultural production depends on the use of commercial fertilizers (Viets, 1970). Indeed, agriculturists have substituted chemical fertilizers for land, labor, and other inputs which are less economically attractive. Intensive agricultural management has produced remarkable results in the USA. Whereas the population has increased by 54 million between 1950-1969, the cultivation area decreased in this period from 142 million hectares to 135 million hectares. Equally revealing is that only about 5 percent of the population is actually involved in feeding the nation (Nelson, 1972; Viets, 1970).

Total fertilizer consumption in the USA was 5.5 million metric tons in 1954 increasing to 14.3 million metric tons in 1970. Elemental phosphorus (P) consumption doubled during this period increasing from 0.92 million metric tons to 1.84 million metric tons (Nelson, 1972). On a weight basis elemental phosphorus used is about 1/3 the amount of elemental nitrogen used in fertilizers in the USA.

The decrease in quality of the nation's waterways during this period of rapidly increasing fertilizer consumption has been cited as proof (Nelson, 1972; Viets, 1971; Vollenweider, 1968) that fertilizer usage is directly related to the increased nutrient supply in surface waters. However, concrete evidence to support this indictment is difficult to find in the literature. The case against agriculture is supported by the report of the American Water Works Association Task Force (Task Group 2610P, 1967). They concluded that agricultural runoff was the greatest single contributor of nitrogen and phosphorus in waters. The estimated phosphorus contribution was 0.4 to 4.0 pounds of phosphorus per year per acre for each of the 308 million acres under cultivation in the USA. In contrast, Webber and Elrick (1967), in a review, stated that phosphorus losses from agricultural lands ranged from .003 to 1.0 pounds per acre per year. The discrepancy between these two reports points out the problem of extrapolating data from specific watersheds to large land masses and the need of pin-pointing the source of phosphorus in each waterway before control measures are adopted.

Chemistry of Phosphorus in Soils

Pertinent to the problem of phosphorus pollution by agricultural runoff is the chemistry of phosphorus in the soil. Soil phosphorus can be divided into two broad categories, inorganic and organic. The proportion of phosphorus in these two forms varies widely between soils. Since organic phosphorus is a constituent of the organic matter in soils, its accumulation and loss follow the general pattern of total organic matter (Black, 1968; Thompson et al., 1954). The source of all organic phosphorus is plant and animal residues. Organic phosphorus is higher in the surface soil than in the subsoil and is converted to its inorganic form (mineralized) as the organic matter is decomposed by bacterial action in the soil.

The origin of all inorganic orthophosphate in the earth's crust comes from the class of minerals called apatite (Black, 1968; Buckman and Brady, 1969; Russell, 1961). This mineral is an insoluble calcium phosphate which can exist in several forms. This type formula is $Ca_{10}(PO_4)_6X_2$ where X is usually OH^{-1} or F^{-1} (Fried and Broeshart, 1967; Stumm and Morgan, 1970). The chemical weathering of apatite produces orthophosphate ions, i.e., $H_2PO_4^{-1}$, HOP_4^{-2} or PO_4^{-3}. The predominant ionic species in solution is a function of the pH of the system (Stumm and Morgan, 1970).

The orthophosphate ion reacts with a variety of cations in the soil, e.g., Ca^{+2}, Fe^{+3}, Zn^{+2}, Al^{+3}, etc., to form a series of insoluble compounds (Buckman and Brady, 1969; Russell, 1961; Stumm and Morgan, 1970). In acid soils, phosphate ions interact predominantly with Fe and Al while in alkaline soils, Ca-phosphate compounds predominate. In addition to forming insoluble compounds with soil cations, orthophosphate ions are sorbed on a number of mineral surfaces which greatly reduces its solubility in the soil solution (Black, 1970; Stumm and Morgan, 1970). The result of the reactivity of orthophosphate with the soil components is that the soluble phosphorus concentration in the soil solution is low, usually between 0.1 to 0.01 mg/l phosphorus or less (Biggar and Corey, 1969; Fried and Broeshart, 1967; Russell, 1961). The chemistry of phosphorus dictates that any input of soluble phosphorus to soils either as commercial fertilizer, plant residues or animal manure, remains near the point of application (Black, 1968, 1970; Viets, 1971). The exception is in sandy or peat soils which exhibit little tendency to react with phosphorus (Black, 1968; Ozanne et al., 1961; Spencer, 1957).

An example of the nonmobility of phosphate fertilizer when applied to the surface of a soil is shown in Figure 14. The data show that after a normal growing season the phosphate fertilizer applied in spring is confined to the surface 5 cm of soil. A continued use of phosphate fertilizer can be expected to result in a buildup of the total phosphorus content in the surface soil. This condition is enhanced by the fact that normally only 5-15 percent of the phosphorus applied as fertilizer is available for plant growth (Buckman and Brady, 1969; Russell, 1961). The remaining 85-90 percent of the applied fertilizer is converted to slightly soluble compounds or surface complexes which constitute the bulk of the inorganic phosphorus in the surface soil.

Evidence exists which suggests that some organic forms of phosphorus, e.g., farm manure, have a greater mobility in soils than inorganic phosphorus. This apparent increased mobility is ascribed to the incorporation of phosphorus into soil microorganisms during the breakdown of the organic matter (Hannapel et al., 1964). This area probably needs more investigation, especially since animal manures are and will be applied to agricultural lands as a method of disposal.

Phosphorus in Field Drainage Effluent

Phosphorus chemistry precludes the possibility of a large concentration of phosphorus being found in tile drain effluent. However, considerable variation is found suggesting many factors are involved in determining the final phosphorus concentration in tile effluent that is monitored. Johnston et al. (1965) studied nitrogen and phosphorus in tile drainage effluent in the San Joaquin Valley of California. Irrigated plots were

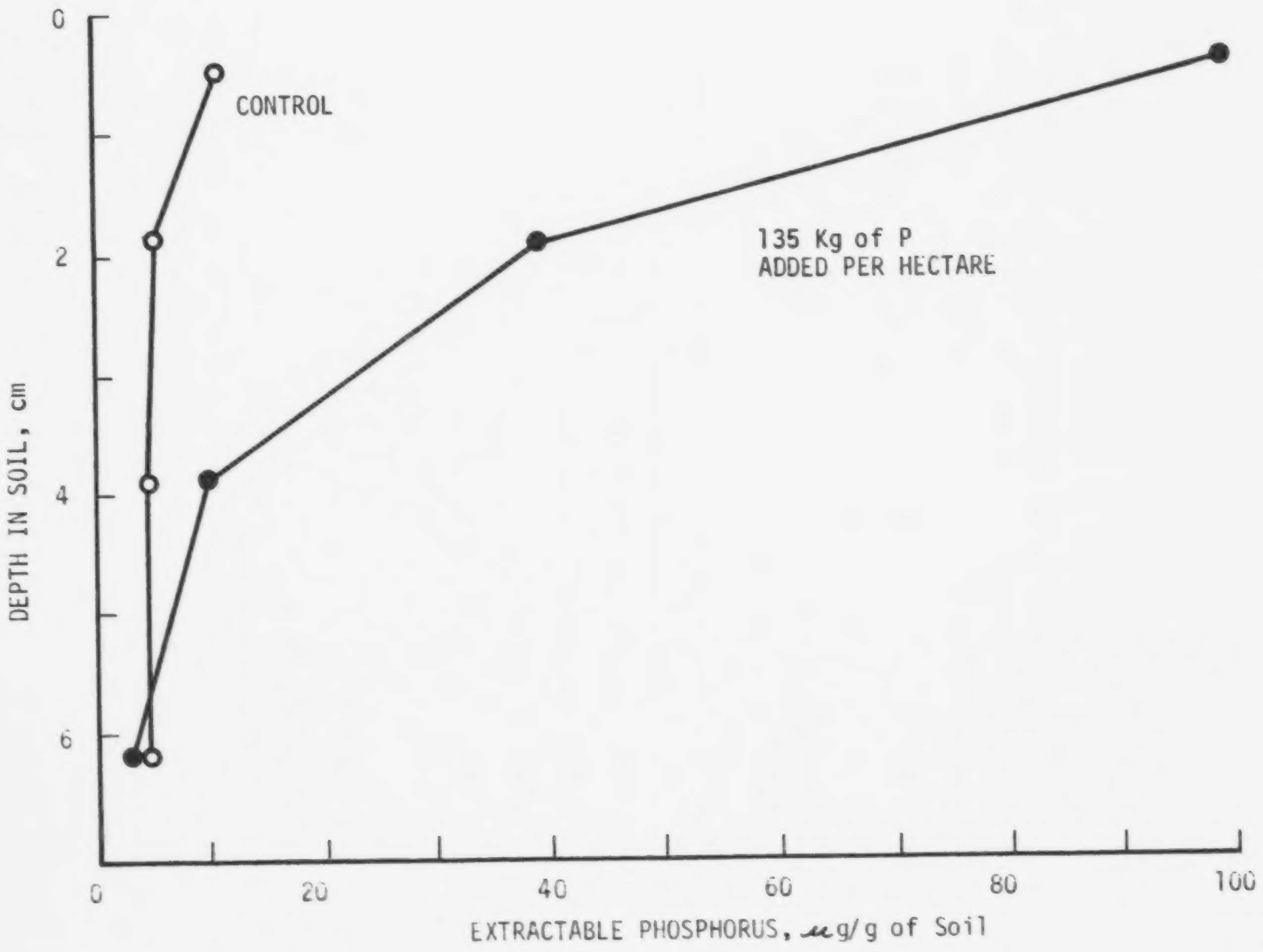


Figure 14. Vertical distribution of extractable phosphorus in control and surface applied phosphorus fertilized soil in Wisconsin. Taken from Black (1968).

subjected to various fertilizer and crop sequences. The mean average of soluble phosphorus found was 0.08 mg/l phosphorus with a range of 0.05 to 0.23 mg/l. The area had received considerable commercial fertilizer over a period of 30 years; the soils were deep, permeable, and calcareous. The tile depth varied from 5.5 to 7.0 feet in the various plots.

A similar type experiment, under natural humid rainfall conditions, was conducted by Zwerman et al. (1972) near Aurora, New York. The soil was predominantly a moderately well drained silt loam with the tile set at about 4.5 feet. The phosphorus concentration ranged from only 0.004 to 0.001 mg/l phosphorus in the effluent. In both of these studies the rate of phosphorus applied was high, about 32 kg/ha as elemental phosphorus; yet a large difference was found in the maximum amount of phosphorus monitored. The inference from these data is that intensive agriculture requiring high amounts of fertilizer and irrigation water would be suspected in terms of phosphorus pollution. This conclusion is corroborated by the findings of Sylvester and Seabloom (1963) who studied the Yakima River Basin in Washington.

A total indictment against irrigation agriculture cannot be made. A comprehensive study of the salt and nutrient balance in the Snake River Valley of Idaho was made by Carter et al. (1971). The area studied involved 203,000 acres (82,030 ha) and had been under irrigation for 65 years. All irrigation water is diverted from the Snake River which has an average soluble phosphorus concentration of 0.021 mg/l phosphorus. The soils are calcareous and have a silt loam texture. The total phosphorus input from both commercial fertilizers and irrigation water averaged about 10 kg/ha. The drainage effluent contained phosphorus in the concentration range of 0.002 to 0.005 mg/l phosphorus, with an average concentration of 0.004 mg/l phosphorus. In this case, irrigation removed over 70 percent of the phosphorus in the input water with no evidence of fertilizer phosphorus found in the drainage. Irrigation decreased the downstream phosphorus load which is contrasted to the total salt and nitrogen load, both of which increased.

The amount of phosphorus in the tile effluent reflects quantitatively the solubility of the predominate insoluble phosphate compound which exists under the prevailing conditions in a given soil profile. Because phosphorus in the soil solution is slow to attain equilibrium with the matrix, it is not possible to predict with accuracy the exact compound regulating the soluble phosphorus concentration. Proper soil management gives some control over the amount of phosphorus in the soil solution, e.g., regulating soil pH (Black, 1968; Buckman and Brady, 1969; Russell, 1961). However, a dilemma exists. Agricultural crop production is based on maintaining a maximum amount of phosphorus in the soil solution, whereas the demands of water quality require that the phosphorus concentration be minimal.

The low threshold value of phosphorus required to trigger algal blooms in lakes, i.e., 0.01 mg/l phosphorus (Sawyer, 1947), results in the fact that most drainage effluent can be regarded as a water pollutant. The impact of tile effluent phosphorus on the quality of receiving water can only be assessed in terms of total effluent volume relative to the total volume of stream flow.

The cost of phosphate fertilizer lost by tile effluent drainage is insignificant. If the concentration of the tile effluent is 0.1 mg/l phosphorus, every acre-foot of drainage water represents a loss of about 0.27 lb of phosphorus. If treble superphosphate sells at $90 per ton, fertilizer loss amounts to 6.2 cents per acre-foot of tile effluent. To eutrophy this acre-foot of water (43,560 cubic feet), assuming the threshold value for algal bloom is 0.010 mg/l phosphorus, costs as little as 0.6 cents using treble superphosphate as the nutrient source. Strategies for control of such phosphorus additions will be developed in Section VII.

Phosphorus in Agricultural Land Runoff

It is the consensus that the majority of the total phosphorus load of the nation's waterways results from rural land runoff. The accumulation of phosphorus at the soil surface, in both inorganic and organic forms, is positionally highly vulnerable to transport in particular forms during soil erosion (Armstrong and Rohlich, 1971; Biggar and Corey, 1969; EPA, 1971b; Martin et al., 1970; Taylor, 1967; Viets, 1971; Wadleigh and Britt, 1969). The organic form of phosphorus is particularly susceptible to transport because of the low density of organic matter.

The nutrient load carried by stream sediments depends to a large extent on the fertility level of the soil eroded. A productive soil has a higher concentration of plant nutrients than a nonproductive soil. In addition, eroded soil sediments represent the surface of the soil which contains more nutrients per unit mass than does the soil that remains (Viets, 1971). The composition of sediments is predominantly silt, clay, and organic matter (Holt et al., 1970). Any cultural practice which reduces soil erodability can be expected to reduce the total nutrient load of rural land runoff (Armstrong and Rohlich, 1971; EPA, 1971b, c; Taylor, 1967; Viets, 1971).

Both soil management practices and types of crops grown influence the amount of runoff as well as the amount of constituents in agricultural land runoff. An example of this is shown by the data of Weidner et al. (1969) in Tables 5 and 6. Table 5 shows that during a 4-year rotation, the two years in meadow showed a marked decrease in field runoff particularly under the prevailing cultural practices. Improved management which included contour tillage, liming and increased fertilizer application, also showed a marked effect in reducing runoff. The improved management practices tended to reduce the effect of crop types. Table 6 shows the analyses of the runoff in terms of its constituents. These data show the importance of a sod crop in terms of both soil erosion and nutrient loss from land. Since suspended solids (sediments) in surface water is considered a major water pollutant in its own right, the principle of continuous ground cover in water quality control is clearly evident. The data of Weidner et al. (1969) also show that despite the increase in fertilizer and manure applied, a marked decrease occurred in pollution load. This supplies evidence that existing technology can provide a means of reducing agricultural pollution when applied in the proper situation. Correspondingly, Johnston et al. (1965) showed the similar effect of management and cropping pattern on both surface and drainage effluent. These data are shown in Table 7. System 6 was in cotton-rice and 7 was in cotton, whereas systems 14 and 16 were alfalfa and rice respectively. The importance of surface runoff in terms of total phosphorus loss is

Table 5. EFFECT OF MANAGEMENT PRACTICE (PREVAILING AND IMPROVED) AND CORN CROP ON RUNOFF IN A 4-YEAR ROTATION[a]

Crop	Av. Monthly Runoff (inches)		Total Runoff (inches)	
	Prevailing	Improved	Prevailing	Improved
Corn	0.43	0.20	2.31	1.09
Wheat	0.21	0.14	1.95	1.29
Meadow	0.10	0.07	3.51	2.41
Total Runoff for 4-year Rotation			7.77	4.79

[a] Taken from Weidner et al. (1969).

clearly shown. These data show that phosphorus was removed from the irrigation water by the soil. System 16 shows that phosphorus lost in the tile effluent was considerably greater than surface runoff. This occurred because the rice system was flooded during much of the period giving a strong bias to the drainage tile data.

Although a definite relation exists between the total phosphorus load in a given water and soil erosion, the question remains whether phosphorus associated with suspended particles is equally available to algae as soluble phosphorus. If the organisms are in direct contact with the sediments, results show that adsorbed or particulate phosphosus can be utilized (Porcella et al., 1970). However, when suspended particles settle out, the associated phosphorus may become positionally unavailable unless mixing of the waters occurs (Holt et al., 1970b; Martin et al., 1970; Zicher et al., 1956).

Table 6. ESTIMATED ANNUAL AMOUNTS OF CONSTITUENTS IN RUNOFF FROM RURAL LAND AS AFFECTED BY MANAGEMENT PRACTICE (PREVAILING OR IMPROVED) AND COVER CROP[a]

	Cover	TS #/acre	BOD #/acre	COD #/acre	PO_4 #/acre	Total N #/acre
Improved	Corn	3,600	27.5	480	8.4	88
Prevailing	Corn	13,220	120.0	1,300	27.7	237
Improved	Wheat	480	3.7	64	1.1	11
Prevailing	Wheat	1,730	15.5	170	3.6	31
Improved	Meadow	Trace	Trace	Trace	Trace	Trace
Prevailing	Meadow	Trace	Trace	Trace	Trace	Trace

[a] Taken from Weidner et al. (1969).

Table 7. NITROGEN AND PHOSPHORUS BALANCE IN TILE DRAINED SOILS[a]

System	Element	Pounds Applied		Pounds Lost		Applied element loss, %
		Fertilizer	Irrigation Water	Drainage Effluent	Tailwater	
6 Cotton-Rice	N	22,216	1,263	14,836	1,539	70
	P	4,025	373	25	109	3
7 Cotton	N	14,112	347	843	414	9
	P	2,328	54	3	11	1
14 Alfalfa	N	0	1,317	282	132	31
	P	0	165	6	16	13
16 Rice	N	3,864	1,357	1,528	191	33
	P	0	156	22	4	17

Sediments are not nutrients, but they do affect the nutritional status of water. Inorganic sediments can serve as both a source and sink for soluble phosphorus, and thus act as a control or buffer to large concentration changes. The efficiency of this phosphorus buffer action depends to a large degree on the thermal or mechanical mixing required for continual water-sediment interaction. The majority of data indicates that most sediments are phosphorus deficient in relation to overlying waters and actually scavenged phosphorus reducing its concentration in solution (Grissinger and McDowell, 1970; Harter, 1968; Holt et al., 1970a; Latterell et al., 1971; Taylor, 1967). Whether inorganic sediments add or remove soluble phosphorus depends on the degree with which contacting water is saturated with respect to the phosphorus associated with the suspended particles. Hence, sediments originating from soils managed under an intensive fertilizer program can be expected to be greater potential sources of soluble phosphorus than those originating from soils under natural vegetation (Armstrong and Rohlich, 1971; EPA, 1971b; Viets, 1971). The data suggest that the source and nature of rural runoff is of prime importance in determining phosphorus abatement strategies for various waters.

Phosphorus in runoff has been associated with seasonal variation. Spring snowmelt runoff has been shown to carry greater amounts of phosphorus than during other times of the year. This has been observed both under agricultural and natural conditions (Hanson and Fensfer, 1969; Holt et al., 1970a; Martin et al., 1970). Most of the phosphorus is considered to originate in plant residues that accumulate during winter on the frozen soil. The phosphate released by these residues does not have sufficient time to interact with the semi-frozen soil during the spring runoff period. Snow runoff in Minnesota (Hanson and Fensfer, 1969) has been shown to have about five to six times more soluble phosphorus (0.16 mg/l) than water which had percolated through soil (0.03 mg/l)

The runoff source of soluble phosphorus from agricultural lands may be more significant than previously considered (Armstrong and Rohlich, 1971; Biggar and Corey, 1969; Martin et al., 1970; Weibel et al., 1966). It appears that any management practice which incorporates fertilizer, animal manures, or plant residues in the soil will reduce the soluble phosphorus load in the runoff. An example of how soil management affects phosphorus in runoff is given as follows (Holt et al., 1970):

Fertilizer Application	Total Phosphorus (mg/l) in Runoff
Control (no fertilizer)	0.08
Broadcast and plowed under	0.09
Broadcast and disked in	0.16
Broadcast (no application)	0.30

These data show that surface fertilization materially increases the phosphorus load and that the deeper the incorporation of the fertilizer in soil the less the effect of fertilizer application. In this study even the control was adding a considerable amount of soluble phosphorus in the runoff.

It is difficult to assess the true status of phosphorus in agricultural land runoff as it contributes to the eutrophication of receiving water. Most reported data fail to discriminate between soluble phosphorus, adsorbed or particulate phosphorus, and organic phosphorus. In addition, total runoff and sediment volume are necessary to determine the total contribution of land runoff to the nutrient load of a stream. Total phosphorus content of runoff does not provide the necessary information since only the soluble orthophosphate form is readily available for organism metabolism. The other forms of phosphorus in the system create a reserve or pool which can be drawn upon when needed or they can serve as a sink to tie up phosphorus in a form not readily available.

Pesticides

The switch from DDT to other types of pesticides as a result of the ban on the use of DDT and probable coming bans on other chlorinated hydrocarbon pesticides has led to an increase in the use of organophosphorus pesticides. Generally, these pesticides are composed of 10-12 percent of phosphorus by weight and thus a measurable input of phosphorus to the waters of interest can be calculated. The hydrolysis of organophosphate pesticides produces a quantity of esterified phosphates which are not available for the growth of algae. However, hydrolysis of phosphate pesticides can go all the way to orthophosphates.

The total quantities of organophosphorus pesticide sales (one can assume sales are equivalent to use) in the U.S. are listed in Table 8. The total amount of organophosphorus pesticides sales since 1967-1970 was 142 million kg and an average of 36 million kg per year. The quantity of sales was variable over the four years, but it can be expected that the quantities will increase in the coming years as the result of probable coming bans on other common chlorinated hydrocarbon pesticides. However, in terms of the possible phosphorus input from such use, the quantity of phosphorus is essentially immeasurable (4 million kg/year or about 0.1 percent of the total USA consumption of phosphorus); this input is included for completeness of the analysis.

Table 8. SALES OF ORGANOPHOSPHORUS PESTICIDES (U.S. TARIFF COMMISSION)

Year	Phosphorus[a] use, million kg/yr	Million kg/yr as Pesticide			
		Total	Parathion[b]	Methyl Parathion[c]	Other
1967	3.1	28	7	14	7
1968	4.2	38	9	20	9
1969	4.6	42	?	23	19
1970	3.7	34	7	18	9

[a] Assume total pesticide is about 11 percent P.

[b] Parathion is $C_{10}H_{14}NO_5PS$, P approximately 10 percent.

[c] Methyl parathion is $C_8H_{10}NO_5PS$, P approximately 11 percent.

URBAN AND RURAL WATERSHEDS

Nonurban Watershed Runoff

Because of the paucity of data on phosphorus output from natural and other kinds of nonurban watershed areas, it was decided to make some quite arbitrary decisions concerning such runoff. First, the nonurban watershed was divided into four separate groups: natural watersheds, developed watersheds, grazing lands watersheds, and managed forests watersheds. These areas were all considered as separate entities and information relating to their relative distribution in a particular basin was obtained from the Water Resources Council (1968).

Managed forests would include those forests where fertilizers are applied and high rates of production are desired (Cooper, 1969). Grazed watersheds would consider those kinds of areas where low density animal grazing occurs as for lands administered by the U.S. Forest Service and the Bureau of Land Management. These lands are located primarily in the western part of the United States. These areas have population densities of 2-5 cows per square mile and serve primarily as a multi-use type of forest land. Developed watersheds include all those kinds of urban, suburban, and recreational construction which are beginning to occur, particularly in high mountain areas, e.g., condominiums and ski developments. Campsites and other high intensity recreational use of watersheds involving people and disposal of their wastes are included in this area. McGauhey et al. (1971) showed that for the Lake Tahoe Basin such developments produced approximately twice as many nutrients as undeveloped watersheds.

All undeveloped or undisturbed watersheds are considered natural watersheds. Any watershed areas which were not subject to forest management, grazing, or development were considered natural watersheds. Levels of nutrient concentration were estimated using data from Likens (1972), Likens et al. (1964), and McGauhey et al. (1971). The other kinds of watershed areas were related by the use of simple factors; assuming that developed watersheds would produce the most runoff phosphorus, and that there were some data indicating this would be about twice the level for the natural watershed (McGauhey et al., 1971), it was decided that managed forests and grazed watersheds would be approximately midway between natural and developed watersheds. Therefore, for developed, grazed, and managed forest watersheds, factors of 2, 1.5, and 1.5 were used to relate them to natural watershed runoff.

By directing runoff from the disturbed watersheds through a natural watershed, it might be possible to control some of this runoff phosphorus. However, in most cases, the amount of phosphorus coming in from the natural and disturbed watersheds would not be significant in comparison to other activities in the basin. If they were significant, it would be likely that little could be done to control eutrophication in that particular basin. One last point concerning watersheds would be that if sufficient management controls were applied to agricultural usages of fertilizer and crops, it would be possible to reduce the agricultural watershed to the equivalent of the nonurban watersheds; these represent a lower limit for agricultural runoff phosphorus concentrations.

Urban Runoff

The analysis of urban runoff is based entirely on the excellent work of Weibel et al. (1969). Their study was quite comprehensive and answered many of the kinds of questions that this project required to identify phosphorus concentrations in runoff. Weibel et al. noted that a runoff factor of 0.37 corresponded to the amount of impervious surface in the urban watershed and in addition noticed that phosphorus concentrations of 0.36 mg/l in runoff water were obtained in spite of the fact that rainfall concentrations average about 0.08 mg/l. This indicated a relatively high input of phosphorus from urban, social, and cultural activities was occurring.

Some of these inputs might be the large pet population in the United States and their fecal material (estimated 40-50 million household cats and dogs in the USA), the use of phosphorus-containing deicing compounds (Struzeski, 1971), and the use of fertilizers around the home for lawns and gardens. Control of these kinds of inputs to urban runoff phosphorus might be exercised by the following list of management proposals. However, they do not seem feasible and little further discussion will occur.

1. Control of animal populations in urban areas appears to be necessary for a variety of reasons, including humane ones. Pets can contribute relatively high concentrations of phosphorus in a relatively small area. In addition, their capacity for possible disease transmission and other nuisance problems seems relatively high. Eventually, it seems that control of such pet populations is likely to be necessary.
2. Use of other compounds other than phosphorus compounds in deicing seems to be an unlikely necessity because the amount of phosphorus used in deicing is relatively small (Struzeski, 1971).
3. Use of home fertilizers represents a relatively uncontrollable source of phosphorus to the basin. Changes in life-style seem necessary here, but their likelihood seems doubtful. Lawns and luxuriant gardens seem to be an important part of our culture, and fertilizer is a major part of the development of these. Use of urban green belts and green areas, such as is practiced in Denver and around Washington, D. C., seems a feasible solution and can be compared to similar proposals

for agricultural croplands. It would be expected that such areas would provide many additional benefits in addition to removing a lot of the phosphorus and other pollutional contaminants of urban runoff. Transferring urban runoff to reservoirs within cities such as is practiced in Denver seems to be a logical step, especially for those areas where combined sewers are a problem. Some of the problems Denver has experienced could be profitably studied to obtain information of use to a city anticipating such "runoff reservoirs."

Solid Waste Disposal

This particular question is specific to landfill and to open dumps, but is not an important one in terms of the overall phosphorus input to natural lake systems. It is possible that for particular lakes or drainage systems it will be important, but this is unlikely and it is only included here for the sake of completeness. Also, it is possible to minimize the output of phosphorus from landfills relatively easily--this would probably be done because of more serious pollutants contained in landfill runoff.

The control feature of leachate recycle (if physically possible) is a significant finding if this source of phosphorus is important in terms of mass contributed to surface waters. Design of landfills to incorporate recycle might be required because of the need for controlling other pollutants (BOD, nitrogen) in the leachate. A detailed analysis of leachate phosphorus is contained in Appendix B.

DOMESTIC ACTIVITIES

Domestic utilization and disposal of phosphorus almost exclusively involves human wastes and washing products. Except for septic tanks and the possibility of direct discharge (in combined sewer overflow or direct disposal) all of this phosphorus enters the municipal treatment plant. After some short discussion of the characteristics of domestic wastes, the factors involved in waste treatment of phosphorus and the program utilized to calculate treatment costs and efficacy will be discussed in this section.

Characteristics of Domestic Wastewater

Domestic wastewater refers to the liquid wastes entering a sewer system from residences, business buildings, and institutions. The water typically carries a total solids concentration of 800 mg/l, of which about 70 percent is dissolved. Approximately 50 percent of the total solids is organic matter and 60 percent of this fraction is biodegradable, exerting a biochemical oxygen demand (5 day, $20^{\circ}C$) of 200 mg/l. The principal groups of organic substances found in sewage are proteins (40-60 percent), carbohydrates (25-50 percent), and fats and oils (10 percent). A wide variety of synthetic molecules may also be present in significant amounts, for example, surfactants. The major inorganic constituents of the water are ammonia nitrogen (20 mg/l), phosphorus (10 mg/l), chlorides (50 mg/l), and alkalinity (100 mg $CaCO_3$/l). The inorganic ions as well as many of the synthetic organic chemicals are not removed by present-day treatment processes.

The concentration of total nitrogen in domestic raw wastewater is generally in the range of 15-90 mg/l with an average of about 40 mg/l. Most of the nitrogen is initially combined in proteinaceous matter and urea. Free ammonia is rapidly formed by biological decomposition. Nitrate is found in only low concentrations in fresh sewage. The total phosphorus concentration ranges from about 2 to 25 mg/l with an average of about 10 mg/l. Thirty to 50 percent is derived from human waste and 50-70 percent from detergents containing phosphate builders. When sodium hexametaphosphate or other phosphorus compounds are used as corrosion and scale control chemicals in water supplies, phosphorus concentrations may be up to 20 percent higher. Usually 85 percent or more of the phosphorus is in the form of orthophosphate.

Human Wastes

Mean per capita human waste values have been calculated by Vollenweider as follows:

Phosphorus = 2.18 g/capita day

Nitrogen = 10.8 g/capita day

The N:P weight ratio would be about 5:1; this is out of balance for phosphorus in relation to optimum algal growth requirements (15:1). These ratios compare with the average N:P ratio of about 4:1 in domestic waste. The 4:1 ratio occurs because other activities (detergent use) add phosphorus to domestic waste. Usually detergents supply about 50 percent of the phosphorus in sewage; thus the total of 4.36 g/capita day times a volume of about 115 gals/capita day of wastewater volume provides 10 mg/l of total phosphorus. A specific estimate of a suburban community in Utah gave 2.7 g/capita day from human waste and 3.5 g/capita day from detergent use (Porcella et al., 1973). Because it was suburban and also because little dilution from other activities occurred, these values will not be used herein.

Household Detergent Use

As shown in Figure 15, use of synthetic detergents increased linearly from 1945 to about 1957 and thereafter until 1968, but at a lesser rate. Soap usage has declined to a relatively constant value constituting about one-sixth of the market by 1968. Difficulties in classifying such cleaning products as to their use by different segments of the U.S. community, and by their content of phosphorus, makes it difficult to adequately assess the use of phosphorus in this particular area (Table 9). Note: Detergent builder formulations, toxicity, and other problems of detergents have been considered previously and will not be discussed herein (Jenkins et al., 1972). If one estimates the total phosphorus use from the production of chemicals that could be used in detergents (Table 10) one would obtain an estimate of 300×10^6 kg of phosphorus. Assuming that 80 percent of the phosphorus in these chemicals is utilized by the soap and detergent industry, as was the case in 1967, this would indicate that in 1970 use of phosphorus by soap and detergents would be in the range of 240 million kg. Dividing by the population for that year (204 million) one obtains a rough estimate of 1.2 kg of phosphorus used per capita year (3.2 g/capita day) in the use of cleaning products. A further subdivision can be made based on commercial-industrial use where it is estimated that in 1970 20 percent of all cleaning products phosphorus

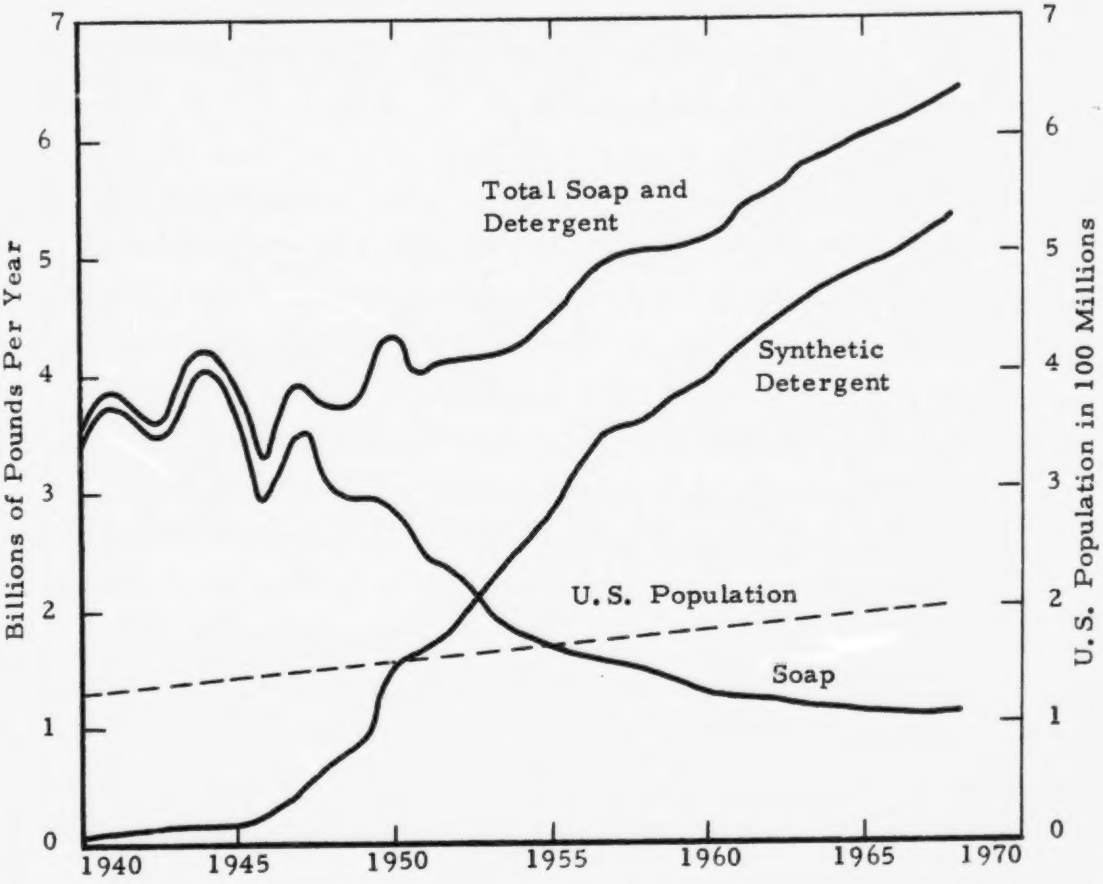


Figure 15. Sales history of soaps and detergents. (From Jenkins et al., 1972.)

Table 9. 1970 ESTIMATED DISTRIBUTION OF PHOSPHORUS BY PRODUCT CLASS OF ALL DETERGENTS/CLEANERS[a]

	%
Household	
Synthetic Heavy Duty Granules	68.0
Machine Dishwashing	4.2
Heavy Duty Liquids/Liquid Cleaners	2.9
Scouring Cleansers	1.7
Powdered Cleaners and Miscellaneous	3.8
Subtotal Household	(80.6)
Commercial/Industrial	
Machine Dishwashing	6.6
Synthetic Heavy Duty Granules	4.6
Miscellaneous, Alkaline Cleaners, Liquids and Cleanser	6.2
Subtotal Commercial	(17.4)
Unclassified	(2.0)
TOTAL	100.0

[a] Based on 1967 Census of Manufactures and information on typical product formulations of 1970. Table taken from Duthie (1973).

were utilized in this area, and 80 percent in households. Thus, on a per capita basis, 0.96 kg of phosphorus per capita year was utilized in the household and 0.24 kg per capita year was utilized in the industrial sector.

Because of the wide variety of washing products, particularly with respect to phosphorus content, further analysis of the detergent question

Table 10. TOTAL U.S. PRODUCTION OF SELECTED PHOSPHATE CHEMICAL (1970)[a]

	10^6 kg P
Trisodium phosphate	9.1
Tetrasodium pyrophosphate	11.6
Sodium tripolyphosphate	273.0
Tetra potassium pyrophosphate	6.6
	300.3

[a] Data taken from U.S. Department of Commerce, 1972. Analysis provided by Duthie (1973).

required some classification. A rather arbitrary classification into soaps, no phosphate detergents, low phosphate detergents, and high phosphate detergents was made. Estimates of the proportion utilized by different segments of the population were obtained as follows: (1) The fraction of population using soap was estimated from production curves in Figure 15 but was rounded to 0.1; (2) the fractions using detergent were estimated for populations in jurisdictions which had enacted legislation restricting phosphate content of detergents. Those results represent the fraction of the population using detergents which use high, low, or non-phosphate detergents as being 0.78, 0.18, and 0.04, respectively. Correcting to the total population (i.e., including soap users) and rounding off one obtains a crude distribution of high, low, and non-phosphate detergents and soap users of 0.7, 0.1, 0.1, and 0.1.

WASTE TREATMENT OF MUNICIPAL SEWAGE

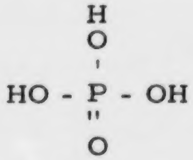
Phosphorus Removal by Chemical Precipitation

Removal of phosphorus by chemical precipitation and flocculation has been studied extensively in conjunction with domestic wastewater treatment processes. Up to 99 percent of the total phosphorus has been removed by chemical precipitation with metallic ions. The total phosphorus concentration in the effluent can be reduced to the range of 3.0 to 0.3 mg/l. Multimedia filtration, or split chemical dosing, is normally required to consistently reduce phosphorus residuals below about 1 mg/l. Relatively low capital costs and moderate operating costs make these processes especially attractive for new or existing treatment facilities that are intermittently required to reduce effluent phosphorus concentrations to meet stream standards. The major liabilities of these methods are the difficulties introduced by the additional inorganic sludge mass and the increase in total dissolved solids in the effluent.

Chemistry--

Phosphorus exists in three forms in domestic wastewater; orthophosphates, condensed inorganic, and organic phosphates.

The "orthophosphates" are defined as those phosphorus-containing compounds or ions which are derived from orthophosphoric acid, H_3PO_4:

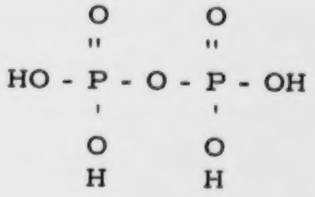


$$\begin{array}{c} \mathrm{H} \\ \mathrm{O} \\ | \\ \mathrm{HO - P - OH} \\ \| \\ \mathrm{O} \end{array}$$

In solution the protons will dissociate from the compound and the concentrations of the various ionic forms which exist are determined by the hydrogen ion activity. HPO_4^{-2} is by far the dominant form in typical wastewater. Orthophosphates constitute from 50-90 percent of the total phosphorus in secondary wastewater effluent (Culp and Culp, 1971; Sawyer, 1960).

Condensed phosphates, e. g., polyphosphates, are derived from orthophosphates by combination of one or more orthophosphate units with the elimination of water, e. g.:

pyrophosphoric acid



$$\mathrm{HO}-\underset{\substack{| \\ \mathrm{O} \\ \mathrm{H}}}{\overset{\substack{\mathrm{O} \\ \|}}{\mathrm{P}}}-\mathrm{O}-\underset{\substack{| \\ \mathrm{O} \\ \mathrm{H}}}{\overset{\substack{\mathrm{O} \\ \|}}{\mathrm{P}}}-\mathrm{OH}$$

Polyphosphates can be looked upon as polymers of phosphoric acid from which water has been removed. Complete hydrolysis results in formation of orthophosphate. The polyphosphates gradually hydrolyze in aqueous solution and revert to the ortho form. The rate depends on temperature, pH, and the original form. Polyphosphates may also be hydrolyzed by biological activity. In a well stabilized secondary effluent, condensed phosphates normally constitute no more than 10 percent of the total phosphorus present (EPA, 1971a; FWPCA, 1969).

The biomass in biological treatment processes contains about 1-3 percent phosphorus. Decomposition of this material releases orthophosphates. In general, conventional treatment processes remove 0-30 percent of the total influent phosphorus by biological assimilation and settling (Directo, Miele, and Masse, 1972; Kaufman and Humerick, 1970).

The chemistry of phosphorus removal by interactions with metallic ions is complex and not completely understood. Orthophosphates will react with lime and form a calcium-phosphate precipitate as represented by the following equation:

$$5Ca^{+2} + 4OH + 3HPO_4^{-2} \rightarrow Ca_5OH(PO_4)_3\downarrow + 3H_2O$$

The precipitate has the basic structure of a hydroxyapatite; however, the Ca to P atomic ratios in the solid material are found to vary from 1.3 to 2.0. The hydroxyapatite is almost completely insoluble at pH levels above 9.5 (Culp and Culp, 1971).

Orthophosphates will combine with aluminum ions to form insoluble aluminum phosphate. Alum ($Al_2(SO_4)_3$) tends to neutralize the pH of the water and the final pH is a function of the buffering capacity (alkalinity) of the water. Therefore, the Al:P ratio necessary for treatment will depend to some extent on the chemical characteristics of the water. In typical wastewaters and at optimum pH of 5.5 to 6.5, Al:P atomic ratios from 1.3 to 3.0 have resulted in phosphorus reductions of from 75-95 percent. Alum is the most common source of aluminum, although sodium aluminate ($NaAlO_2$) is an alternate source (EPA, 1971a).

Ferric and ferrous ions can also be used to precipitate orthophosphate. In typical wastewaters with pH adjusted to the optimum range of 5 to

5.5, Fe:P molar ratios from 1.5 to 3.0 have resulted in phosphate reduction of 75-95 percent. Experience has indicated that ferrous ion is required in about the same amounts. Good removals can also be obtained at higher pH's.

Polyelectrolytes, or polymers, are frequently used to improve the flocculation and clarification of the precipitate. The usual dose is about 0.10-0.50 mg/l. Characteristics of the flocculation may also be improved by recycling a portion of the sludge (Thomas, 1972).

The polyphosphate ions, in general, do not form particularly insoluble salts with metallic ions unless there is a relatively high ratio of metals to polyphosphates. A significant amount may be removed, however, by sorption on flocculation particles (EPA, 1971a).

Methods and Costs--

Numerous schemes have been suggested for the chemical precipitation of phosphorus in conventional waste treatment facilities. These schemes generally differ in the type, amount, and point of addition of the metallic ions. In the following discussion, methods have been grouped into broad categories to facilitate the presentation of cost data. More detailed information about specific processes can be found in the references (Culp and Culp, 1971; EPA, 1971a).

Chemical Addition to Raw Wastewater--

Addition of chemical coagulating agents to raw wastewater may significantly increase the removal of organics and phosphorus during primary sedimentation. Total phosphorus removal may be increased from 5-10 percent to 70-90 percent; suspended solids removal increased from 40-70 percent to 60-75 percent, and BOD removals increased from 24-40 percent to 40-50 percent. Where organic loading is primarily in the form of suspended solids, this chemical-physical type process may be able to replace secondary biological treatment, at little, if any, additional cost, and provide a significantly greater reduction in phosphorus. With the addition of carbon adsorption and dual media filtration following primary clarification, 97 percent BOD and 90 percent total phosphorus reduction may be achieved (Convery, 1970; Weber et al., 1970; Bishop et al., 1972).

A 7,200 gpd pilot plant consisting of ferric chloride coagulation, clarification, dual media filtration and carbon adsorption in series was operated on raw sewage for one year. Consistent removal rates of 97 percent BOD, and 90 percent total phosphorus were maintained. Effluent phosphorus concentrations were about 5 mg/l. Costs, in part estimated from previously published data and adjusted to June 1967, are shown in Table 11 (Weber et al., 1970; Smith, 1968).

A 100,000 gpd pilot plant consisting of lime coagulation, two-stage clarification with intermediate recarbonation, dual media filtration, ion exchange and granulated carbon adsorption was operated on raw wastewater from Washington, D.C. The two-stage lime process alone consistently reduced the phosphorus concentration from about 8.5 mg/l to 0.45 mg/l. The estimated costs for a 300 mgd plant based on 1970 prices are shown in Table 12. Costs include sludge incineration and 50 percent lime recovery (Bishop et al., 1972).

Table 11. COSTS ASSOCIATED WITH 90 PERCENT TOTAL PHOSPHORUS REMOVAL FROM RAW WASTEWATER (WEBER ET AL., 1970). PROCESS INCLUDES FERRIC CHLORIDE COAGULATION, CLARIFICATION, DUAL MEDIA FILTRATION AND CARBON ADSORPTION IN SERIES[a, b, c]

Plant Size mgd	Process Cost (Capital) $1,000			
	Preliminary Treatment	Coagulation-Sedimentation	Filtration	Granulated Carbon
1.0	15	52	90	380
10.0	65	400	410	1600
100.0	250	3200	1900	6800
	Process Cost (Operating) ¢/1000 gal			
1.0	29			
10.0	16			
100.0	10			

[a] Include amortization charges, 4.5 percent, 25 years.

[b] Costs adjusted to June 1967.

[c] Not including sludge disposal.

A complete review has been conducted covering the performance and costs associated with the addition of chemical coagulants to the raw wastewater influent to conventional activated sludge plants (EPA, 1971a).

Table 12. COSTS ASSOCIATED WITH PHOSPHORUS REMOVAL FROM RAW WASTEWATER BY LIME COAGULATION, TWO-STAGE CLARIFICATION AND ADDITIONAL ADVANCED PROCESSES (BISHOP ET AL., 1972)

Item	Process Costs ¢/1000 gal[a]						
	Pump and Grit	Lime Treatment[c]	Filtration	Solids Disposal	A. C. Adsorption	Ion Exchange[d]	Total
Operations and Maintenance	0.48	1.7	0.6	2.3	2.8	2.8	10.4
Chemicals	-	2.2	0.3	0.1	-	2.6	5.2
Capital Cost[b]	0.6	4.1	1.0	1.5	4.8	4.6	16.6
Total	1.1	8.0	1.9	3.9	7.6	9.7	32.2
Total Phosphorus in effluent mg/l	8.5	0.45	0.2		0.15	0.15	

[a] 300 mgd, June 1970 costs.

[b] Annual capital cost computed at annual rate of 8 percent including interest and amortization.

[c] Sludge incineration, 50 percent lime recovery.

[d] Ion exchange (clinoptilolite) primarily for nitrogen removal.

Significant increases in efficiency can be obtained by adding the coagulant at two points; before primary and before secondary clarification. In comparison to conventional systems, the amount of primary sludge increases and the secondary sludge decreases. Generally, sludge filterability is about the same as for sludges without mineral addition; however, in the case of lime addition, the waste activated sludge may be more difficult to dewater.

Up to 93 percent removal of the total phosphorus can be achieved by the use of alum (Al:P of 1.5-3.0) plus an anionic polymer. Phosphorus residuals in the effluent can be reduced to 0.5 mg/l. Phosphorus removal of 60-80 percent can be obtained by the addition of iron coagulants (Fe:P of 1.5-2.0) and polymers. High concentrations of Fe may remain in the effluent. These high concentrations have been reduced by adding lime to increase the pH to about 8 before clarification. Alum and iron have been used successfully without the addition of flocculation basins before the primary clarifier (EPA, 1971b).

In plants providing secondary treatment, phosphorus removal by lime is limited to about 80 percent because pH's greater than 10 in the flow from the primary clarifier to activate sludge may adversely effect the biological process. Increased settling of suspended solids plus the chemical sludge may result in up to 300 percent the normal amount of sludge in the primary clarifier.

Average costs associated with the addition of chemical coagulants to the raw wastewater stream in conventional treatment plants are shown in Table 13. Prices do not include additional sludge handling facilities.

Table 13. COSTS ASSOCIATED WITH 80 PERCENT REMOVAL OF TOTAL PHOSPHORUS FROM RAW WASTEWATER IN CONVENTIONAL TREATMENT FACILITIES (CONVERY, 1970)[a, b, c]

Plant Size mgd	Capital Costs (Fe or Al)		Capital Costs (Ca)		Chemical Cost ¢/1000 gal		
	$1000	¢/1000 gal	$1000	¢/1000 gal	Fe	Al	Ca
1	21	.446	58	1.6	3.6	4.2	1.4
10	72	.154	241	0.7	3.6	4.2	1.4
100	697	.149	926	0.3	3.6	4.2	1.4

[a] Amortization of capital cost at 6 percent over 25 years.

[b] Chemical costs include polymer.

[c] Not including additional sludge handling facilities.

Chemical costs based on assumed 80 percent phosphorus removal with 1.5:1 atomic ratios of Al:P and Fe:P and for 150 mg/l dosage of CaO. The minimum total operating cost is probably about 1.0¢/1000 gallons (Convery, 1970).

Chemical Addition Preceding Secondary Treatment--

Methods of adding chemical coagulants to primary clarifier effluent preceding activated sludge treatment have been reviewed in detail (EPA, 1971a). Dosages of metal ions in the atomic ratios, Al or Fe: orthophosphate of 1.5-3 have resulted in phosphorus residuals of 3.5-0.3 mg/l. Calcium does not appear to be an effective precipitant because the pH required for calcium phosphate precipitation is higher than the optimum range for biological activity in the aerator.

Alum addition of 2.3:1, Al:P, has given an average reduction in total phosphate concentration from 10-1.4. Mixtures of alum and lime may be more effective than pure alum in some cases (Srinath and Pillai, 1972). Sludge has increased 1.5 to 2 times normal conventional amounts but has better thickening qualities. Volatile suspended solids in the aerator sludge are reduced from about 80 percent of total suspended solids (conventional) to about 60 percent of TSS (with alum coagulating). Total operating costs for alum additives depend on the characteristics of the wastewater and on the quality of the effluent. Assuming no capital costs are required, approximately 3.1¢/1000 gallons will achieve an effluent quality of 3.3 mg/l and 8.0¢/1000 gallons a quality of 0.3 mg/l.

Studies have been conducted with the addition of ferric chloride to an activated sludge plant serving a population of 20,000 in Uster, Switzerland. The addition of 7.7 mg/l ferric chloride plus the recycling of some ferric phosphate sludge has resulted in reducing total phosphorus an average of 85 percent with an effluent residue of 0.46 mg/l (Thomas, 1972). Iron content in the discharge water ranged between 0.1 and 0.6 mg/l. The ferric sludge helped thicken the activated sludge and little increase in total sludge volume was experienced. No release of soluble phosphorus from the sludge has been observed due to reduction of the ferric ion during anaerobic digestion (Singer, 1972).

Studies at a 2.2 mgd activated sludge plant in Pomona, California (Directo et al., 1972), indicated that the conventional system removed approximately 13 percent of the total phosphorus leaving a residue of 10 mg/l in the secondary effluent. With the addition of 1.9:1 atomic ratio of Al:P (in the form of alum) directly to the aerator, the phosphorus removal ranged from 60 to 84 percent with an average value of 75 percent. The average concentration in the secondary effluent was 2.9 mg/l. No increase in efficiency was observed with the addition of anionic or cationic polymers. Sludge mass increased 1.95 times the conventional amount, but excess sludge volume did not increase. The inorganic fraction of the mixed liquor suspended solids increased from 17 to 42 percent. At the same plant, tests with ferric chloride indicated an average of 80 percent removal with a Fe:P atomic ratio of 1.5:1. Residual total phosphorus in the effluent was 2.2. The mass of sludge produced was approximately twice that of conventional; however, the volume of waste sludge did not increase appreciably. Fe:P atomic ratios greater than 3:1 were observed to interfere with the biological removal of BOD. Phosphorus residue concentrations in the secondary effluent could be reduced to about 1.2 mg/l by polishing with a two-stage pressure sand filtering system. Chemical costs for alum and ferric chloride in the secondary system at various levels of residual dissolved phosphate concentrations are discussed below. The cost of polishing sand filtration for a 10 mgd plant was estimated at 4.6¢/1000 gallons. To achieve 90 percent phosphorus removal with a wastewater containing 10 mg/l of phosphorus, the alum costs would be 2.4¢/1000 gallons (alum at 24¢/lb) at a mole ratio of 1.4:1 Al:P. Total operating and maintenance costs would be about 3.6¢/gallon.

Tertiary Treatment by Chemical Coagulation of Secondary Effluent--

Tertiary treatment is accomplished by adding chemical coagulants to the secondary effluent in a rapid mixing basin followed by flocculation, single or two-stage sedimentation, and mixed media filtration. Depending on the process, pH adjustment may be necessary at various stages. A state of the art survey has been conducted and details of the various processes are presented in the report (EPA, 1971a).

Lime doses are usually in the range of 300-400 mg/l as CaO for two-stage treatment, and from 150-200 mg/l where single-stage treatment is satisfactory. The amount of P removed is a function of pH which is related to the alkalinity of the water. Therefore, the lime dose depends to a large extent on the alkalinity of the influent. The two-stage clarification system at South Lake Tahoe, California (Culp and Culp, 1971), which has a capacity of 7.5 mgd, can routinely maintain an effluent with a phosphorus concentration of about 0.4 mg/l before the filters and less than 0.1 mg/l after filtration. Table 14 shows costs based on data

Table 14. COSTS ASSOCIATED WITH LIME TREATMENT OF SECONDARY EFFLUENT (EPA, 1971a; CULP AND CULP, 1971; SMITH AND MCMICHAEL, 1969)[a, b]

Total Cost for Lime Treatment of Secondary Effluent

Treatment	Cost (¢/1000 gal) Plant Size (mgd)		
	1	10	100
Single-stage w/o filtration	13	7	4
Two-stage w/o filtration	16	9	6
Dual media filtration	8	3	1.4

Capital Costs

Treatment	Cost ($) Plant Size (mgd)		
	1	10	100
Single-stage w/o filter	100,000	1,200,000	5,500,000
Two-stage w/o filter	160,000	1,500,000	7,900,000
Dual media filtration	110,000	510,000	2,300,000

[a] Capital costs updated to December 1970. Amortization is at 6 percent for 25 years.

[b] Recalcination equipment not included in 1 mgd plant, no cost included for sludge disposal.

obtained from Tahoe and other sources. Recalcination of the sludge is probably not economical for plants with capacity less than 10 mgd.

Alum dosages of 50-100 mg/l (Al:P atomic ratio of 1:1 to 2:1) are sufficient to produce a residual phosphorus concentration of about 1 mg/l by settling alone. Residuals may be reduced to less than 0.1 mg/l by multimedia filtration. Estimated costs are shown in Table 15 (Ross, 1970). Economical methods have not as yet been developed for recovering Al or Fe from the sludge.

Studies at the Pomona tertiary plant with ferric chloride (Directo et al., 1972) indicated that Fe:P atomic ratios of 1.5:1 would result in about 84 percent removal of total phosphorus with a residual concentration of about 1.6 mg/l in the effluent stream after filtration. The addition of 0.2 mg/l of an anionic polymer was necessary to obtain a good flocculation. Solids-liquid separation became more difficult at Fe:P atomic ratios exceeding 2.2:1. Efficiency in total phosphorus removal was increased by adding the ferric chloride to both the primary and secondary effluents. Removals of 96 percent with phosphorus residuals of 0.5 were obtained by the split addition of chemicals with Fe:P ratios of 1.5:1. The ferric ion concentration in the effluent averaged about 2.4 mg/l. Estimated chemical costs are discussed below.

Experiments have been successful in removing phosphorus from trickling filter effluents by chemical coagulation. Ferric chloride dosages sufficient to provide Fe:P atomic ratios of 2.5 to 3.75 resulted in about 85 percent removal with phosphorus residuals of 0.1-6 mg/l (Keinath, 1972). Chemical costs were estimated at 3¢/1000 gallons for $FeCl_3$. Phosphorus removal can be increased to 97 percent with consistent effluent residuals of 0.2-0.5 mg/l by the addition of multimedia filtration. Costs to provide 90 percent phosphate removal with alum for 50 mgd

Table 15. COSTS ASSOCIATED WITH ALUM COAGULATION (WITH POLYMER) OF SECONDARY EFFLUENT. PROCESS DOES NOT INCLUDE SEDIMENTATION; FLOCCULATION IS FOLLOWED DIRECTLY BY MIXED-MEDIA FILTRATION AND ACTIVATED CARBON ADSORPTION (EPA, 1971a)[a]

Process	Total Unit Costs ¢/1000 Plant Capacity (mgd)		
	1	10	100
Coagulation	4.9	3.5	3.2
Filtration	1.8	1.1	1.0
Carbon adsorption	6.3	4.5	4.0
	13.0	9.1	8.2
Operating labor	28.0	5.6	1.8
	41.0	14.7	10.0

[a] Estimated costs include an annual charge of 8.5 percent of the capital cost for debt service and maintenance combined. Based on February 1970 prices.

flow in a 75 mgd plant with dual media filtration were estimated at 6.5-8.2¢/1000 gallons (EPA, 1971a).

Other Tertiary Methods

Ion Exchange--

The Pomona, California, ion exchange pilot plant is a strong-acid weak-base process designed for the reduction of total dissolved solids (Dryden, 1970). Phosphorus removal is outstanding, with a reduction of 8.8 mg/l to 0.1 mg/l (98.8 percent). Total dissolved solids are reduced from 611 mg/l to 81 mg/l (86.7 percent). Average costs for a 10 mgd plant are shown in Table 16.

Experiments using strong-acid cation and weak-base anion ion exchange columns indicate costs ranging from 6.7 to 23.8 ¢/1000 gallons, depending on the extent of treatment and alkalinity of the water (EPA, 1971c). Phosphorus reductions of 6.1 mg/l to 0.16 mg/l were obtained using lime coagulation as a pretreatment at an average cost of 18¢/1000 gallons. Without lime pretreatment reductions of 6.1 mg/l to 0.65 mg/l were obtained at a cost of 15.3¢/1000 gallons. Activated carbon adsorption (40-60 percent removal total organic carbon) precedes the ion exchange columns to prevent resin clogging.

Activated alumina has been used successfully to selectively remove the forms of phosphate normally found in wastewaters including orthophosphate, pyrophosphate, tripolyphosphate, and hexametaphosphate (Yee, 1966). Effluent concentrations of 0.07 mg/l to 0.14 were obtained at chemical costs of 3.9¢/1000 gallons for 14 mg/l removal and 6.4¢/1000 gallons for 23 mg/l removal, based on 8 percent loss of alumina during each regeneration cycle.

Table 16. ESTIMATED COSTS FOR A 10 MGD ION EXCHANGE PLANT (DRYDEN, 1970). TOTAL DISSOLVED SOLIDS REDUCED FROM 700 MG/L TO 75 MG/L AND PHOSPHORUS REDUCED FROM 9 MG/L TO 0.1 MG/L

	¢/1000 gal
Capital Cost	
$1,370,000; 20 years @5%	3.0
Operation and Maintenance	
Chemicals	16.2
Operation and Maintenance	2.8
Total	22.0

Table 17. ESTIMATED COSTS FOR A 1 MGD SELECTIVE ION EXCHANGE PLANT (EPA, 1970a). INFLUENT CONCENTRATION OF 10 MG/L REDUCED TO NOT MORE THAN 0.32 MG/L[a]

Capital Cost = $221,970	
Cost Per 1000 Gallons	
Capital Cost	7.61
Chemical Cost	17.71
Operating and Maintenance	9.06
Total Cost	34.38

[a] Based on plant life of 30 years at 4½ percent interest.

Other experiments using selective ion exchange processes have demonstrated the reduction of phosphorus content from 10 mg/l in the influent to not more than 0.32 mg/l in the effluent at a cost of about 35¢/1000 gallons for a 1 mgd plant (EPA, 1970a). Estimated costs are shown in Table 17.

Reverse Osmosis--

Reverse osmosis is a process in which water is separated from dissolved salts in solution by filtering through a semipermeable membrane at a pressure greater than the osmotic pressure caused by the dissolved salts in the wastewater. Operating pressure varies from atmospheric to 1,500 psi.

The reverse osmosis process provides excellent removal of dissolved solids. In the Pomona, California, pilot plant (Dryden, 1970) total dissolved solids were reduced from 759 mg/l to 59 mg/l (92.1 percent) and phosphorus was reduced from 10.9 mg/l to 0.2 mg/l (98.4 percent). Costs associated with this process are shown in Table 18. Although these costs are relatively high in comparison to those of other methods, improved membranes could considerably increase the efficiency. Other estimates indicate TDS reduction greater than 90 percent and phosphate reduction greater than 99 percent at costs in the range of 30-60¢/1000 gallons (EPA, 1970b). Costs estimated for the reverse osmosis process for water reclamation in a closed system are shown in Table 19 (Besik, 1971).

Table 18. ESTIMATED COSTS FOR A 10 MGD REVERSE OSMOSIS PLANT (DRYDEN, 1970). INFLUENT TDS REDUCED FROM 750 MG/L TO 59 MG/L AND PHOSPHORUS REDUCED FROM 10.9 MG/L TO 0.2 MG/L

Capital Cost	¢/1000 Gallons
$4,020,000; 20 years at 5%	8.8
Operation and Maintenance	
Chemicals	7.3
Membrane Replacement	14.4
Other	11.1
Total	41.6

Table 19. COST ESTIMATES FOR REVERSE OSMOSIS (BESIK, 1971). TOTAL DISSOLVED SOLIDS REMOVAL FROM 585 MG/L TO 24 MG/L (96 PERCENT) AND PHOSPHORUS REMOVAL FROM 1 MG/L TO 0.1 MG/L (90 PERCENT)[a, b]

	Plant Size (mgd)		
	0.1	0.5	1.0
Capital Cost	80,000	336,000	617,000
Total Treatment Costs ¢/1000 Gal	40.0	27.0	22.0

[a] Based on 4.5 percent for 25 years in June 1967.

[b] Brine disposal not included.

Electrodialysis--

In the electrodialysis process, ionic compounds of a solution are separated through the use of semipermeable ion-selective membranes. Application of an electrical potential between the two electrodes causes an electric current to pass through the solution, which, in turn, causes a migration of cations towards the negative electrode and a migration of anions towards the positive electrode.

Pilot plant operations at Pomona, California, indicate reduction of total dissolved solids from 705-465 (34 percent) and phosphorus from 10.1 to 7.8 (23 percent). Because of the low removal rates, it was concluded that electrodialysis is not competitive with ion exchange or reverse osmosis (Dryden, 1970). Costs are shown in Table 20.

Soil Spreading--

Where adequate land is available at reasonably low cost, soil spreading may be an efficient method for the disposal of secondary treatment plant effluents. In pilot plant studies near Phoenix, Arizona, effluent from a sewage treatment plant was pumped to six 20 ft by 700 ft plant-soil filters. At a loading rate of 300 acre-feet of secondary sewage effluent per year per acre of filter, about 90 percent of the phosphorus was removed by adsorption to soil particles or by precipitation into the soil profile. The basins were operated on a 14 day wet, 10 day dry cycle to maintain a satisfactory infiltration rate and to allow for reoxygenation of the soil surface. Costs were estimated to be $5/acre-foot (U.S. Department of Agriculture, 1969). Induced percolation of municipal effluent through

Table 20. ESTIMATED COSTS FOR A 10 MGD ELECTRODIALYSIS PLANT (DRYDEN, 1970). COD REMOVAL 15 PERCENT, TDS REMOVAL 34 PERCENT, AND PHOSPHORUS REMOVAL 23 PERCENT

Capital Costs	¢/1000 gallons
$1,830,000; 20 Years at 5 Percent	4.0
Operation and Maintenance	
Chemicals	4.4
Membrane Replacement	3.3
Other	5.3
Total	17.0

a peat soil resulted in from 76 to 92 percent removal of phosphorus. Ferric iron in the soil was probably the principal phosphorus fixation agent. Removal was observed to decrease with time.

INDUSTRIAL USES OF PHOSPHORUS

As was listed in Table 4 only a small amount of the total phosphorus produced by mining activities (approximately 11 percent) enters the industrial cycle. As shown in Table 21 there are a myriad of industrial uses, only a few of which are both significant and enter surface waters.

Metal finishing wastes represent phosphoric acid used as an improvement in certain operations over sulfuric acid for etching, cleaning, and metal plating operations. Frequently such operations are, or should be, required to treat their wastes in-plant as source control of metals wastes. Phosphorus will probably be removed in metals waste treatment. Estimates of phosphoric acid use in such processes indicate that its use will likely increase; however, that should constitute a negligible input of phosphorus because of the in-plant waste treatment.

Use of phosphorus in food and pharmaceutical compounds can probably be ignored because it represents a human use and as such will be included in the human waste component.

Use of water softening compounds has increased with the increased industrial uses of cooling water and other thermal applications. However, use of phosphorus-based softening compounds has been static apparently since 1958 (Jenkins, 1973). In addition, the discharge of softened industrial water is probably minimal because of the economic value of recycling treated water where possible. Also, depending on the type of phosphate softening compound, there will be no discharge (a sludge is formed) or if hexametaphosphates, for example, are used, soluble complexes will be formed and these could enter the water supply if discharged. Thus, although certain types of water softening compounds can be considered a point source discharge, and these can be treated at a municipal treatment plant, it is probably a minimal problem and the use of the phosphorus-bearing water softening compounds may gradually decrease to zero without any pressure from regulatory agencies. Certainly, the addition of supply and demand pressures (Section VII) might hasten the decrease in its use if such action seemed necessary.

Table 21. INDUSTRIAL USES OF PHOSPHORUS IN 1968 BASED ON LEWIS (1970) AND LOGUE (1958)

	Estimated P use 1000 Kg/yr	Likelihood of entering surface waters[a]
Metal Finishing Wastes	94.	c
Food and Pharmaceutical (includes soft drinks, toothpaste, shaving cream, baking powder)	58.	c
Water Softening	35.	c
Other Miscellaneous Uses	293.	c
Rat poisons	--[b]	a
Matches	--	a
Flame retardents	--	a
Plastics (plasticizers)	6.4	a
Gasoline additives	0.5	d
Bone china	--	a
Dyes for textiles	9	b
Glass	--	a
Photographic film and chemicals	--	b
Military uses	--	b
Silk fabrics	--	a
Sugar processing	--	b
Oil refining	--	b
Pesticides	4	d
Total	426	

---

[a] a = not likely; b = doubtful; c = point source to surface water; d = diffuse source to surface water.

[b] Dashes indicate not estimated.

The other uses of phosphorus in manufactured products with the exception of pesticides--described elsewhere in this section--have been grouped into a category called miscellaneous uses. Loss of phosphorus from the industries manufacturing these products is considered to be a proportion (0.5) of the total amount utilized in the category.

Strictly speaking, the food processing industry is not an industrial use of phosphorus. Because it is an industry and food contains phosphorus which may, due to the possible hydrolysis of organic phosphorus compounds in the process of biological treatment, be liberated from food wastes, this industry is considered in this section. It is probably not a significant source of phosphorus to surface waters because of the more important problem of high BOD and the low concentration of phosphorus in foods (~ 1 percent by weight). Also, it is unlikely that phosphorus release from foods is significant except over long term biological activity.

All of these industrial uses are essentially minimal compared to other phosphorus inputs to surface waters. The only really significant phosphorus use in industry involves industrial detergent. Estimates of such use are frequently quite crude because of the wide range of cleaners utilized by the great number of different industries. For example, one estimate was 0.23 kg/capita year (see detergents). Another estimate can be obtained by subtracting the total domestic use (204×10^6 people $\times$ 0.800 kg/capita year (from Vollenweider, 1968) = 1.64×10^5 kg/year) from the total phosphorus use in the detergent industry (2.27×10^5 kg/year); this indicates that industrial use would be about 28 percent of the total detergent use in the USA. This value is not too much different from the approximately 20 percent industrial use estimate of detergent use by commercial/industrial applications and unclassified uses shown in Table 9.

Use of industrial detergents and other industrial phosphorus uses are probably similar to any generalized water use in industry, i.e., the water is collected and discharged directly into the sewer or into the surface water system. Although it is possible to require in-plant treatment, such a requirement seems impractical. Consequently, all industrial uses are added to the municipal waste stream, where applicable, or discharged to the surface water.

MINING ACTIVITIES AND PHOSPHORUS USE

The mining and processing of phosphorus is distributed throughout most regions of the USA; for example, phosphoric acid production is the major phosphorus processing industry and is distributed as shown in Figure 16. The principal producing states are Florida, Idaho, Tennessee, and North Carolina. The estimated total consumption of mined phosphorus was 3159 metric tons (Lewis, 1970); although U.S. Department of Commerce (1972) estimates were 3451 for 1968, Lewis' number was used because of his closer relationship to the industry.

Processing produces many waste streams, some of which are recycled in the mining and refining processes and some of which are discharged to settling ponds, or where dilution is sufficient, to surface waters (Figure 17). Most of the waste streams are treated for fluoride removal and phosphorus removal and the incentive is primarily economic.

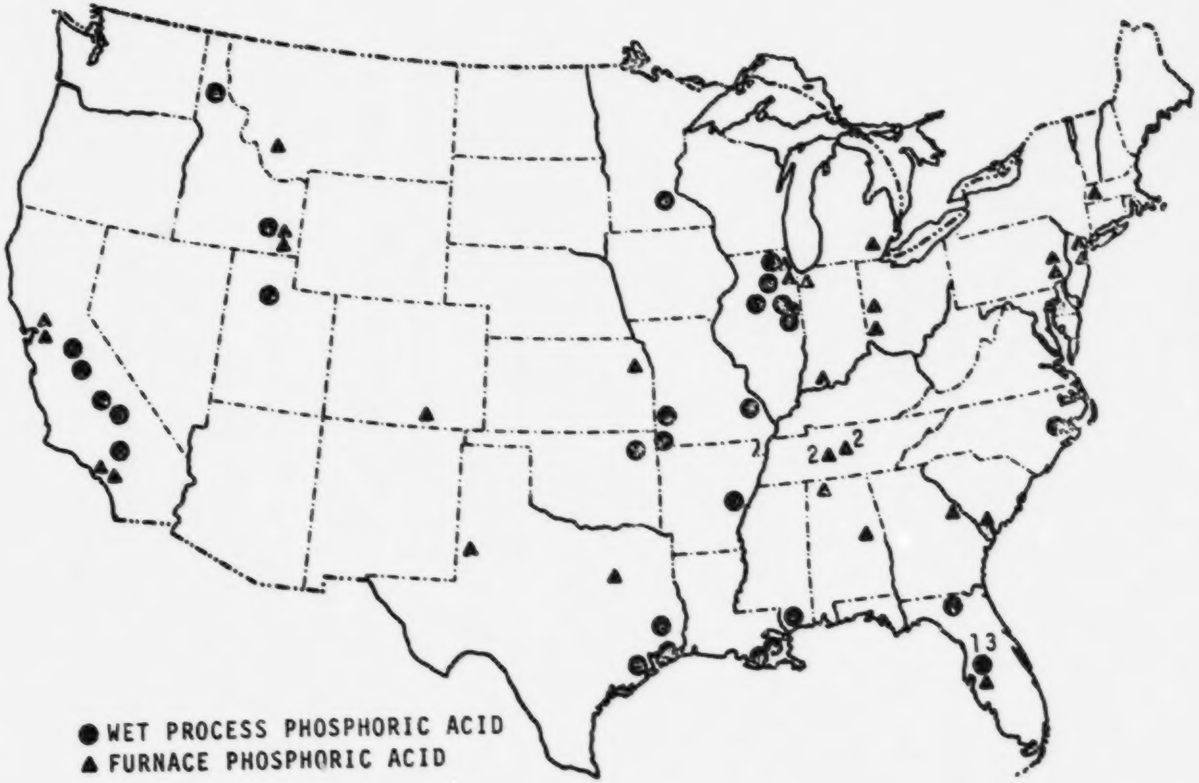

● WET PROCESS PHOSPHORIC ACID
▲ FURNACE PHOSPHORIC ACID
2
2
2
13

Figure 16. Location of major phosphoric acid plants in the United States (taken from Fullam and Faulkner, 1971).

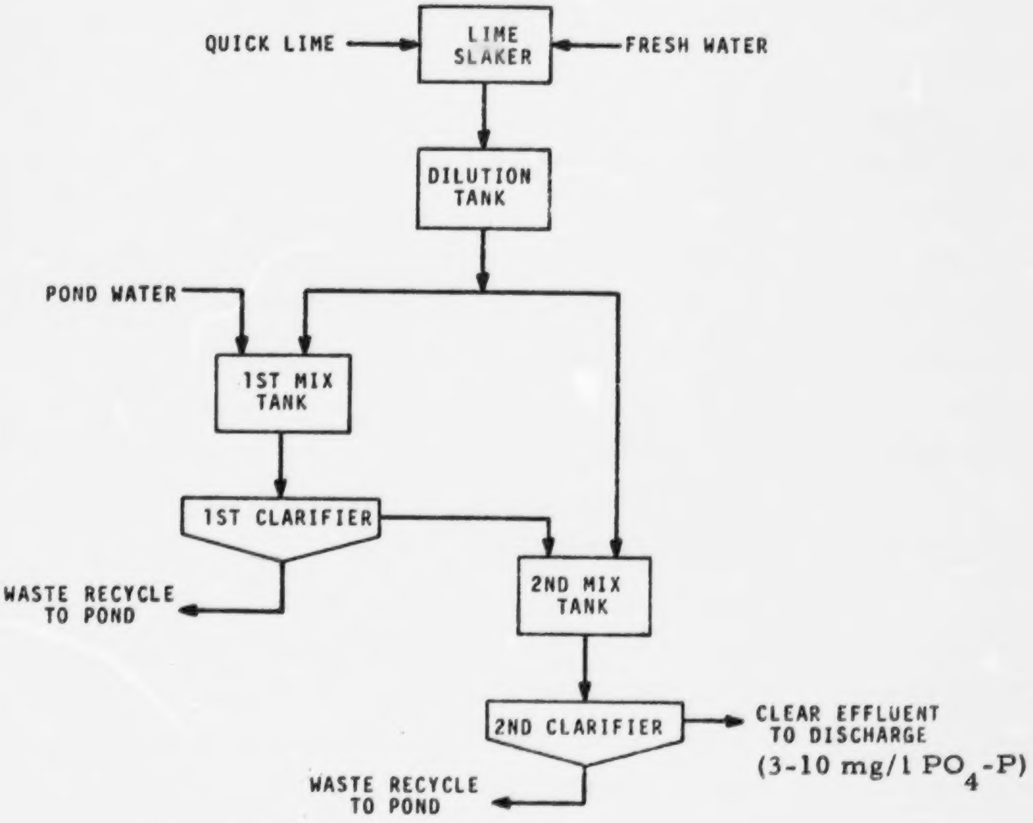

QUICK LIME
LIME SLAKER
FRESH WATER
DILUTION TANK
POND WATER
1ST MIX TANK
1ST CLARIFIER
WASTE RECYCLE TO POND
2ND MIX TANK
2ND CLARIFIER
CLEAR EFFLUENT TO DISCHARGE
(3-10 mg/l PO_4-P)
WASTE RECYCLE TO POND

Figure 17. Flowsheet for lime neutralization of gypsum pond water (adapted from Fullam and Faulkner, 1971).

Application of water quality standards has enforced a closed cycle type of operation on mining activities; direct discharge of phosphorus-bearing wastes is negligible in the absence of spills and settling pond dike failure. Costs of treating effluents (lime precipitation) to current acceptable water quality standards with dilution (3-10 mg/l phosphate P) averages about $1.90 per short ton of P_2O_5 produced (Fullam and Faulkner, 1971).

Specific regions will require significant effort to prevent phosphorus mining effluents from affecting water supplies. Because of the importance of the industry to the national economy and the fact that it is a point source and easily located, stringent discharge controls seem to be a reasonable requirement.

ANIMAL WASTES AND PHOSPHORUS

Background of the Problem of Animal Waste Disposal

Historically, the major effort has been devoted to the control of pollutional problems caused by urban centers, such as industrial pollution, domestic liquid waste, solid wastes, and storm water runoff. Agricultural related environmental quality problems have received little attention until the last ten years, and perhaps this lack of attention is attributable to a point of view that control of pollution from agriculture was impossible, or that the contribution was insignificant and should not be considered along with the much more complex problems produced by the urban centers. It is possible that this rather naive observation would have allowed us to ignore the agricultural problem for many more years had agricultural practices remained static.

However, remarkable changes have taken place in the United States with respect to methods of agricultural production (Loehr, 1972). Farm size and productivity per farm worker have increased significantly, and intensive crop and animal production have taken on essentially the same characteristics of an industrial complex. Because of this increased efficiency of agricultural production, a variety of environmental problems have developed. Also, increased production of agricultural products are being encouraged as a result of balance of payments question. It is now quite obvious that this increase in agricultural production has had detrimental effects on environmental quality. Furthermore, the influx of suburbia into rural areas has made many more people aware of the problems generated by handling and disposing of agricultural wastes.

The intensive agricultural practices and the public awareness of the degradation of the environment caused by agricultural waste disposal practices has forced legislatures and the federal government to recognize these problems and all of the recent legislation directs specific controls toward solving agricultural pollution problems. Most of the legislation has been prepared with the point that control of agricultural sources of pollution must be carried out in a manner that will allow agriculture to continue to produce at a rate that is adequate to avert food shortages. The legislation also insists that adequate controls be provided to protect the environment, or provide an environment acceptable to the public.

Many attempts have been made in the past ten years to evaluate the effect of the changes in agricultural production procedures on the environment. Many conflicts are apparent when one considers the alternatives that must be evaluated. However, it is essential that the agricultural producer be aware of the consequences of his waste disposal practices when new facilities are constructed. Many of the existing problems caused by agricultural practices could have been prevented if proper land use laws had been prepared many years ago. The construction of many of the feedlots and intensive agricultural activities such as poultry raising could have been prohibited from developing in their present locations if proper planning had occurred.

The management of animal wastes would be much simpler if a significant proportion of the contribution were concentrated in feedlots so that the wastes could be handled at one location. This is not the case in many sections of the U.S. where small dairy and beef cattle feeding operations are carried out in relatively isolated areas separated by great distances. The majority of these small dairy and beef feedlots are located along small streams and use the stream as a means of disposing of their excess manures. Many of these operations in the past used manure spreading as a means of disposing of a proportion of their manure, but with the advent of inexpensive artificial fertilizers, it is no longer advantageous to dispose of animal manures by spreading them on the ground. Also, as the operation becomes larger it is more difficult to utilize the entire production of manure on the land. This necessitates hauling the manure to other land disposal sites or attempting to sell the material as a soil conditioner. Little success has been achieved in commercial enterprises attempting to dispose of significant quantities of animal manures. All of the difficulties that are involved in disposing of excess manure have contributed significantly to the quantities of manure that eventually reach our water courses, deplete the oxygen supply, and add excessive quantities of nitrogen and phosphorus which stimulate algal growth.

New recommended regulations developed by the Environmental Protection Agency make an attempt to control the contribution of all types of agricultural wastes. It is a noble gesture on the part of the federal government and some of the state agencies to attempt to control the discharge of manures to our waterways. However, that these agencies will have success in enforcing these regulations is doubtful. The ability to monitor the waste discharges from industrial and municipal sources is limited in the majority of the United States, and the federal government has little effort and manpower involved in monitoring activities when the entire picture is evaluated. Therefore, it appears that the only effective control that can be implemented will be the reduction of the waste materials that are discharged from concentrated feedlot and poultry raising operations.

These sources produce large quantities of material that would exhibit a significant effect on the waterways that could easily be detected if the waste were indiscriminately discharged. Pollution resulting from land spreading and eventual runoff would be extremely difficult to identify, and the ability to monitor and control such activities is very limited. If effective control were to be accomplished, a force approximately the size of the production force would be required to insist that pollution or excess nutrients not be discharged to the environment by agricultural activities.

An excellent example of the difficulty that would be encountered in enforcing agricultural practices or agricultural pollution control legislation can be seen in the State of Utah. Here, the majority of the dairy and feedlot operations are relatively small, consisting of less than 50 cows per farm. These installations are located, in the majority of the cases, along the shores of the many relatively small streams that emanate from the mountains. There may be 2 to 20 miles between each of these operations and there are many hundreds located in the state. The manpower that would be required to periodically inspect and ensure that enforcement activities are carried out would be economically prohibitive. The situation in the State of Utah is very similar to the problems that would be found in all of the Intermountain area and much of the other rural areas of the USA.

Similar situations probably exist elsewhere in the United States even where the majority of the animal raising activities are concentrated in massive feedlots. In brief, it appears that the control of nutrients and pollutants from small agricultural operations will have to rely on the integrity of the individual farmer. And as the majority of the small farms are at best marginal profit making operations, it is doubtful that the regulatory agencies can honestly expect a small farmer to devote a significant proportion of his time to managing water quality control facilities.

Considerable interest is being developed in using agricultural lands as a means of disposing of municipal sewages and sludges. If a significant quantity of sewage and sewage sludges are disposed of on agricultural lands, this will contribute significantly to the amount of material that would be classified as agricultural runoff. In general this type of wastewater disposal will be subjected to far better control than is normally exercised in agricultural installations. The source of discharge of wastewater that has been used for irrigated agriculture could be classified more or less as a point source, and the contribution to the overall phosphorus budget of a particular operation should easily be measured and, in turn, more easily controlled.

Characteristics of Animal Wastes

The mass of wet manure produced per gram of animal per day and the solids concentration of wet manures are shown in Table 22 for poultry, swine, dairy cattle, and beef cattle. A comparison of the average weight of wet manure produced per weight of animal per day for all the animals shows that the values range between 0.062 grams for poultry to 0.084 grams for cattle. Considering that the data were collected at different farms and by different investigators, the difference between the average values reported for all of the domestic animals is very narrow, and it could be safely assumed that the production of manure per weight of animal is essentially the same for all domestic animals.

The dry solids content of manures ranged from 0.0079 for dairy cattle up to 0.014 grams of total solids per gram of poultry per day. This range is somewhat wider than the one mentioned earlier for the production of wet manures; however, the differences are not drastic in view of the variability within each of the individual samples. The percentage of total solids by wet weight were the greatest for poultry manures and little difference was noted between the swine and cattle and sheep. The volatile solids percentage of the total solids ranged between 71.8 percent up to 81.7 percent with the lower value representing the poultry and the higher value beef cattle. This variation in volatile content of the solids is probably insignificant if one were attempting to

Table 22. PHYSICAL CHARACTERISTICS OF LIVESTOCK DEFECATION

ANIMAL	Wet Manure g/g of Animal-day	Total Solids g/g of Animal-day	Total Solids % of W W	Volatile Solids g/g of Animal-day	Volatile Solids % of T S.	REFERENCES
Poultry	0.0234	0.011	45.0	-	-	Moore, 1969
	0.027-0.087	0.011-0.022	25-48	0.0084-0.017	74 79	Taiganides and Hazen, 1966
	0.074	0.021	28	-	-	Hart, 1960
	-	0.014	-	0.0098	70	Dornbush and Anderson, 1964
	-	0.013	-	0.0101	77.5	Hart and Turner, 1965
	-	0.013-0.019	-	-	-	Dept. of Sci. and Indust. Res., 1964
	0.072	0.0086	12	0.0054	63	Townshend et al., 1969
	0.083	-	-	-	-	Kearl, 1965
Average	0.062	0.014	30.3	0.0096	71.8	
Swine	0.084	0.011	13.1	-	-	Moore, 1969
	0.028-0.095	0.008-0.016	12-28	0.0068-0.0136	83-87	Taiganides and Hazen, 1966
	0.087	0.016	18	-	-	Hart, 1960
	-	0.0080	-	0.0063	78.5	Hart and Turner, 1965
	-	0.0097	-	0.0080	82.5	Taiganides et al., 1964
	-	0.0050	-	0.0035	70	Clark, 1965
	-	0.0071	-	-	-	Dept. of Sci. and Indust. Res., 1964
	-	0.0048	-	0.0033	68.8	Humenik, 1972
	0.074	0.0059	8	0.0047	79.7	Schmid and Lipper, 1969
	-	0.0099	-	0.0070	71	Townshend et al., 1969
Average	0.074	0.0089	17.4	0.0054	76.5	
Cattle (Dairy)	0.071	0.0114	16.0	-	-	Moore, 1969
(Dairy)	0.058	0.0087	15	-	-	Hart, 1960
(Dairy)	-	0.0104	-	0.0083	80.3	Hart and Turner, 1965
(Dairy)	-	0.0068	-	0.0057	83.8	Witzel et al., 1966
(Dairy)	-	0.0075	-	-	-	Dept. of Sci. and Indust. Res., 1964
(Dairy)	0.124	0.0025	2	0.0018	72	Townshend et al., 1969
(Beef)	0.082	0.0197	24.0	-	-	Moore, 1969
(Beef)	0.039-0.074	0.0095-0.0114	13-27	-	-	Taiganides and Hazen, 1966; Taiganides, 1964
(Beef)	0.063	0.0095	15	-	-	Hart, 1960
(Beef)	0.067	0.0090	15	0.0069	77	Loehr and Agnew, 1967
(Beef)	-	0.0036	-	0.0032	89	Witzel et al., 1966
(Beef)	0.063	0.0050	8	0.0040	79	Townshend et al., 1969
(Beef)	-	0.0091	-	-	-	Dale and Day, 1967
Average (D)	0.084	0.0079	11.0	0.0053	78.7	
Average (B)	0.066	0.0095	16.4	0.0047	81.7	
Sheep	0.072	0.016	23	-	-	Hart, 1960
Ducks	-	0.016	-	-	-	FWPCA, 1966

operate an anaerobic system. However, the nitrogen, COD, and BOD content may indicate this not to be the case.

Table 23 shows the BOD, COD, and nutrient contents of fowl manures in weight per weight of animal per day x 10^{-3}. The results reported by the various investigators vary widely from sample to sample. However, considering that none of the operating characteristics of the animal-raising operations were available, the numbers probably are as good as can be expected. Although wide differences can be shown for each of the constituents, in general the mean values are fairly characteristic of the majority of the data reported and can safely be used in the estimates of the contribution of nutrients to waterways by animal manures.

Table 24 shows the characteristics of swine manures as reported in the literature, and a comparison of the characteristics of swine manures with those of fowl manures indicates that they are quite similar. However, the nitrogen and phosphorus content per gram of animal per day is less than that found in poultry manures. But the BOD and COD content of fowl manures is higher than that found in swine manures.

Table 25 shows the characteristics of cattle manures divided according to beef cattle and dairy cattle. An examination of the mean values for beef and dairy cattle indicates that there is little difference in the BOD, COD, and nutrient content of these manures. In general, the reports in the literature of the phosphorus and nitrogen content of cattle manures were consistent and differed little from one study to the other. However, the differences noted in BOD and COD for the various types of cattle

Table 23. NUTRIENT AND SANITARY CHARACTERISTICS OF DOMESTIC FOWL MANURES

ANIMAL	Characteristics of Fowl Manures g/g of Animal-day x 10^{-3}						REFERENCES
	BOD	COD	Ammonia Nitrogen	Total Nitrogen	Phosphorus P_2O_5	Potassium K_2O	
Poultry	-	-	-	1.12	0.72	0.36	Moore, 1969
	-	-	-	0.27-1.27	0.22-1.00	0.11-0.42	Taiganides and Hazen, 1966
	-	-	-	1.1	-	-	Hart, 1960
	3.33	11.1	0.13	0.67	0.58	-	Dornbush and Anderson, 1964
	2.91	11.2	0.52	0.70	0.60	0.27	Hart and Turner, 1965
	3.33-7.11	-	-	-	-	-	Little, 1966
	1.33-2.22	-	-	-	-	-	Dept. of Sci. and Indust. Res., 1964
	-	-	-	0.23	0.37	-	Vollenweider, 1968
	3.74	7.1	-	0.58	0.72	-	Townshend et al., 1969
	4.27	-	0.12	-	-	-	Kearl, 1965
Average	3.46	9.8	0.26	0.74	0.60	0.30	
Ducks	2.0-4.0	-	-	8.0	0.6-1.6	-	FWPCA, 1966

Table 24. NUTRIENT AND SANITARY CHARACTERISTICS OF SWINE MANURES

ANIMAL	Characteristics of Swine Manures g/g of Animal-day x 10^{-3}						REFERENCES
	BOD	COD	Ammonia Nitrogen	Total Nitrogen	Phosphorus P_2O_5	Potassium K_2O	
Swine	-	-	-	0.51	0.32	0.62	Moore, 1969
	-	-	-	0.42-0.60	0.29-0.32	0.34-0.62	Taiganides and Hazen, 1966
	-	-	-	0.53	-	-	Hart, 1960
	2.0	7.6	0.24	0.32	0.25	0.11	Hart and Turner, 1965
	4.3	5.4	-	0.64	-	-	Taiganides et al., 1964
	-	4.7	-	-	-	-	Clark, 1965
	2.5	-	-	-	-	-	Little, 1966
	2.2	-	-	0.70	-	-	Poelma, 1966
	5.6	-	-	-	-	-	Dept. of Sci. and Indust. Res., 1964
	-	-	-	0.41	0.55	-	Vollenweider, 1968
	3.1	6.4	-	-	-	-	Humenik, 1972
	2.0	5.2	-	-	-	-	Schmid and Lipper, 1969
	3.2	9.3	-	0.44	0.67	-	Townshend et al., 1969
Average	3.1	6.4	0.24	0.51	0.42	0.40	

Table 25. NUTRIENT AND SANITARY CHARACTERISTICS OF CATTLE MANURES

ANIMAL	Characteristics of Cattle Manures g/g of Animal-day x 10^{-1}						REFERENCES
	BOD	COD	Ammonia Nitrogen	Total Nitrogen	Phosphorus P_2O_5	Potassium K_2O	
Beef Cattle	--	--	--	0.36	0.115	0.274	Moore, 1969
	--	--	--	0.35-0.44	0.11-0.12	0.27-0.34	Taiganides and Hazen, 1966; Taganides et al., 1964
	--	--	--	0.29	--	--	Hart, 1960
	1.11-2.22	10.0	--	0.26	--	--	Loehr and Agnew, 1967
	1.02	3.26	0.11	0.26	--	--	Witzel et al., 1966
	--	--	--	0.41	0.25	--	Vollenweider, 1968
	1.87	15.0	--	0.16	0.31	--	Townshend et al., 1969
	1.84	--	--	--	--	--	Dale and Day, 1967
Average	1.61	9.42	0.11	0.32	0.18	0.29	
Dairy Cattle	--	--	--	--	0.30	--	Hart, 1960
	--	1.53	19.1	--	--	--	Jeffery et al., 1963
	0.31	1.53	8.4	--	0.38	0.12	Hart and Turner, 1965
	--	1.32	5.8	0.23	0.37	--	Witzel et al., 1966
	--	0.44	--	--	0.49	--	Dept. of Sci. and Indust. Res., 1964
	--	0.95	5.7	--	0.16	0.11	Townshend et al., 1969
Average	0.31	1.15	9.8	0.23	0.34	0.12	

wastes varied widely between the different studies. This can probably be attributed to the types of feed supplied to the animals. The carbon content could vary quite widely, and in all probability the phosphorus, nitrogen, and potassium contents of the feed would remain essentially the same regardless of the carbon content.

Table 26 shows the characteristics of sheep manure; only two sources of data were found for sheep. These limited data indicate that the nutrient content of sheep manures is relatively high in nitrogen content and essentially the same as the other manures in phosphorus content.

Agricultural Runoff of Manures

Agricultural runoff consists of discharges; which range from almost natural runoff from forests and unused lands to such point sources as confined animal feedlots and fertilized fields. Control of runoff from animal feedlots and fertilized fields generally can be exercised by waste management and land conservation techniques. However, it is almost impossible to do anything about the more general nonpoint discharges such as those discharged from range lands and recreational areas. Because of the difficulty associated with controlling agricultural runoff from grazing lands and recreational areas, the following discussion will concentrate primarily on the contribution from point sources such as confined animal feedlots. It should also be pointed out that soil erosion contributes significantly to the pollution contributed by agricultural runoff. However, this subject will also be omitted from this discussion because it has been covered previously in Section V. Some

Table 26. NUTRIENT AND SANITARY CHARACTERISTICS OF SHEEP MANURES

ANIMAL	Characteristics of Sheep Manures g/g of Animal-day x 10^{-3}						REFERENCES
	BOD	COD	Ammonia Nitrogen	Total Nitrogen	Phosphorus P_2O_5	Potassium K_2O	
Sheep				0.86			Hart, 1960
				0.34	0.25		Vollenweider, 1968
Average				0.60	0.25		

data relating to manures and the contribution of nutrients from natural drainage areas and urban areas will be presented.

It is relatively simple to examine and define the influence of point sources from agricultural industry on water pollution. However, it is extremely difficult to quantify water pollution problems and nutrient contributions resulting from general agricultural runoff. The following presentation will attempt to summarize the results that have been found by several investigators. These results will show the tremendous variability involved in the quantitative results obtained for various installations.

Animal Feedlots

In many areas of the United States, animal manures are still returned to the fields as a source of fertilizer. However, this practice is being eliminated because of the economics involved in disposing of large quantities of animal manures. Also, the large increase in the number of large feedlots that produce animals for slaughter has tended to cause large quantities of manure to accumulate in and around these feedlots. This manure does not present a significant water pollution problem until the wastes are disposed of by spreading on the ground or until they are washed into a receiving body of water.

If runoff from large feedlots is confined to the area, little difficulty occurs. However, the practice in the past has been to encourage draining from the confinement areas into the drainage pattern of the surrounding land. This provided a convenient method of disposing of the manures and solved the disposal problems for the individual farmer. The consequences of such a disposal system, primarily fish kills (e.g., Vollenweider, 1968), were usually ignored by the individual farmer until he was forced to accept the responsibility for the damage that he had caused. The identification of the problems caused by these slug discharges of manures to a stream or impoundment have led enforcement agencies to attempt to develop solutions for these problems.

As mentioned, the quantity and quality of runoff from feedlots is quite variable, and depends on several factors, i.e., soil water content, concentration of cattle on the feedlot, method of feedlot operation, soil characteristics, topography, and intensity of the rainfall (Loehr, 1972). Because of this large number of variables, the characteristics of feedlot funoff are unpredictable, and it is difficult to interpret runoff-pollutional characteristics relationships. In the past few years studies have been conducted that provide information about natural and simulated rainfall events that allow a broad interpretation of the quantity and quality of rainfall runoff under various environmental conditions.

The concentration of nutrients found in manures on feedlots will depend upon the time of year and the age of the manure. During the winter there will be much less decomposition than would occur during the summer months, and a large concentration of pollutants would be expected to accumulate. The characteristics of the runoff from a feedlot will be a function of the physical and biochemical changes that are occurring. The concentrations of the various pollutants in feedlot runoff will be the highest during the initial phase of the rainfall and will decrease as runoff continues. After the feedlot surface becomes covered with manure, the water quality parameters of the runoff are no longer affected by the depth of manure that has accumulated on the surface. The quality of feedlot runoff after the surface is covered is affected by the pollutional constituents in the manures, rainfall intensity, water content of a manure pack, and the type of feedlot surface (Miner et al., 1966).

The results of several studies describing the magnitude and variability of constituents in feedlot runoff are summarized in Table 27. The variability of runoff is illustrated by the range of values reported for the BOD which varied from 500 mg/l to 12,000 mg/l. Solids and nitrogen concentration show even wider variations. The variable nature of the runoff indicates the significant slug effect that these discharges could have on a stream. The slug effects and the use of holding ponds preceding discharge have been evaluated as a means of eliminating some of the impact that slug discharges may exert upon a stream (Gilbertson et al., 1971; Loehr, 1970; Loehr, 1972; Meyers et al., 1972; Wells et al., 1970; Willrich, 1966).

The characteristics of runoff are significantly affected by the environmental conditions in the area of the feedlot. For example, the longer the manure remains wet, the better the chances of biological degradation of the pollutional compounds. The biological degradation is also significantly increased during warmer weather. In dry climates when manure dries out rapidly, the pollutional constituents of the manure remain essentially constant. When the manures are wetted again, the discharge to a water course is essentially the same as it would have

Table 27. FEEDLOT RUNOFF CHARACTERISTICS

ANIMAL	Range of Values for Constituents, mg/l							
	Suspended Solids	Ortho-phosphate PO_4	Organic Nitrogen	Ammonia Nitrogen	Nitrate Nitrogen	BOD	COD	REF
Cattle	3,400-13,400	--	--	--	--	500-3,300	--	Owens and Griffin, 1968
Cattle	--	--	6-800	2-770	0-1,270	1,000-12,000	2,400-38,000	Wells et al., 1970
Cattle	1,000-7,000[a]					300-6,000		Norton and Hansen, 1969
Cattle	--	--	--	--	--	1,500-9,000	4,000-15,000	Loehr, 1969b
Cattle	1,400-12,000	15-80	--	1-139	0.1-11	--	2,500-15,000	Miner et al., 1966
Cattle	--	20-30	600-630	270-410	--	5,000-11,000	16,000-40,000	Loehr, 1969a
Cattle	1,500-12,000	--	--	16-140	--	--	3,000-11,000	Miner, 1967
Cattle	1,400-12,000	62-1,460[b]	265-3,400	--	--	800-7,500	--	Townshend et al., 1970

[a] Volatile solids.

[b] Total phosphorus as PO_4.

been if the material had been discharged at the time it was first deposited on the ground (Filip et al., 1973; Gilbertson et al., 1971; Meyers et al., 1972).

Loehr (1970) has shown that the pollution from an uncovered livestock area is related to the amount of precipitation that becomes runoff and reaches surface streams. The original condition of the manure on the feedlot as well as the slope of the feedlot directly affects the amount of runoff that occurs after a rainfall. A relationship between precipitation and runoff expressed in inches of water at small surfaced and unsurfaced feedlots was described by Loehr:

$$\text{Runoff} = -0.34 + 0.945\ (\text{Rainfall}) \tag{8}$$

Gilbertson et al. (1971) showed that from 0.22 inches to 0.35 inches of precipitation occurred before runoff was detected at cattle feedlots. The relationship between runoff and rainfall in inches of water was found to be:

$$\text{Runoff} = -0.135 + 0.53\ (\text{Rainfall}) \tag{9}$$

All studies of animal feedlot runoff indicate that a small percentage of the oxygen demanding materials in the wastes is removed by runoff. However, the water pollution potential of livestock feedlots is related to the waste production per animal, number of animals confined, and the management practices applied to the wastes discharged on the lots. If cattle were fattened on the range, a much smaller concentration of pollutants in runoff would be detected. However, the trend today is toward more and larger livestock feedlots.

The contribution of pollution from livestock feedlots by runoff can easily be controlled with unsophisticated waste management practices. Proper diking and collection of rainfall runoff in holding ponds can solve the majority of the problems that presently exist. The systems must be designed to prevent overflow except under unusual rainfall conditions, and the liquids and solids collected in the ponds should be disposed of by application to pastures and croplands. If properly operated, such a scheme should essentially eliminate the impact of feedlot runoff on the receiving streams in the vicinity of such an operation. It is unlikely that the expense of using conventional waste treatment techniques for feedlot runoff and animal wastes will be employed in the near future.

Loehr (1972) has recommended a number of feedlot runoff control measures, e.g., diversion, retention ponds, confinement, location, evaporation ponds, and land disposal. It appears that these techniques are the most popular methods of controlling feedlot runoff at this time, and in all probability will remain the most popular as long as land is available, principally because of the economic advantages. If such a system is properly operated and the liquid and manures collected in the retention pond are disposed of properly on the land, the impact on a water course is essentially the same as that reported for agricultural lands used for grazing purposes. Examples of the concentrations of phosphorus and other constituents that may be discharged from various types of runoff are shown in Tables 28-32.

Table 28. ESTIMATE OF NUTRIENT CONTRIBUTIONS FROM VARIOUS SOURCES (GOLDBERG, 1970)

Source	Nitrogen		Phosphorus	
	Pounds per year	Usual concentration in discharge	Pounds per year	Usual concentration in discharge
	(millions)	(mg/l)	(millions)	(mg/l)
Domestic waste	1,100-1,600	18-20	200-500	3.5-9.0
Industrial waste	>1,000	0-10,000	a	a
Rural runoff:				
Agricultural land	1,500-15,000	1-70	120-1,200	0.05-1.1
Nonagricultural land	400-1,900	0.1-0.5	150-750	0.04-0.2
Farm animal waste	>1,000	a	a	a
Urban runoff	110-1,100	1-10	11-170	0.1-1.5
Rainfall[b]	30-590	0.1-2.0	3-9	0.01-0.03

[a] Insufficient data available to make estimate.

[b] Considers rainfall contributed directly to water surface.

Table 29. ANNUAL NUTRIENT LOSS FOR TWO SEASONS FOR THE NATURAL-RAINFALL EROSION PLOTS (TIMMONS ET AL., 1968)

Cropping Treatments	Avg Annual Kilograms Per Hectare Soil Loss	Avg Annual Centimeters Runoff	Avg Kg per Hectare Nutrient Loss				
			Total N[a]	NH_4-N	NO_3-N	P	K
		1966					
Fallow	8,518.0	9.65	29.1	0.33	0.90	0.04	2.0
Corn-continuous	807.0	2.31	4.48	0.11	0.11	0.11	0.56
Corn-rotation	426.0	5.20	2.24	<0.11	0.33	0.11	0.67
Oats-rotation	22.4	0.51	0.11	0.0	<0.11	0.0	<0.11
Hay-rotation	0.0	8.66	0.34	0.0	0.11	0.11	0.90
		1967					
Fallow	23,044.0	11.76	100.8	0.22	0.54	2.9	5.1
Corn-continuous	7,039.0	7.56	21.5	0.34	0.90	0.04	1.3
Corn-rotation	1,389.0	5.96	7.5	0.11	0.08	0.11	0.67
Oats-rotation	2,286.0	5.30	10.5	0.11	0.18	0.11	0.67
Hay-rotation	0.0	9.72	6.4	0.0	0.04	0.33	5.8

[a] Excludes NH_4- and NO_2-N.

Table 30. RANGES OF SOME SELECTED NUTRIENTS IN SEWAGE EFFLUENTS AND LAND DRAINAGE ENTERING THE GREAT OUSE: CONCENTRATIONS IN THE RIVER WATER ARE ALSO INCLUDED (OWENS AND WOOD, 1968)

Nutrient	Sewage Effluent	Land Drainage	River Water
	(mg/l)	(mg/l)	(mg/l)
Carbon (soluble)	6.7-24.0	2.8-8.0	3.5-12.4
Ammonium-N	0.0-48.0	0.0-0.5	0.0-9.8
Nitrate-N	0.0-35.0	5.5-29.4	3.0-14.2
Nitrite-N	0.0-14.5	0.01-0.1	0.01-0.4
Organic-N	0.0-13.6	0.3-0.9	0.0-2.9
Potassium	16.0-32.0	6.0-16.5	6.8-9.0
Total soluble phosphorus	3.0-14.0	0.02-0.3	0.17-0.73
Silicon	1.9-11.0	0.7-5.0	0.07-5.0

Table 31. MEAN NUTRIENT CONCENTRATIONS FROM RUN-OFF SOURCES IN PARTS PER BILLION (SYLVESTER, 1961)

	Total Phosphorus (P)	Soluble Phosphorus (P)	Nitrates (N)	Total Kjeldahl Nitrogen (N)
Urban street drainage	208	76	527	2,010
Urban street drainage (median)	154	22	420	410
Streams from forested areas	69	7	130	74
Subsurface irrigation drains	216	184	2,690	172
Surface irrigation drains	251	162	1,250	205
Green Lake	76	16	84	340

Table 32. SOLUBLE PHOSPHORUS CONCENTRATIONS REPORTED FOR WATERS DRAINING RURAL WATERSHEDS (VERDUIN, 1967)

Author	Type of watershed	Phosphorus concentration μg P/l
Engelbrecht and Morgan, 1960[a]	Farmlands in Kaskaskia River basin, Illinois	60
Engelbrecht and Morgan, 1953[a]	Eight lake and reservoir stations, pollution-free	35
Sylvester, 1961[a]	Forest streams	7
Sylvester, 1961[a]	Irrigated land, return flow drains, Washington	173
Sawyer, 1947[a]	Rural drainage around Lake Mendota, Wisconsin	48
Putnam and Olson, 1960[a]	St. Louis and Black rivers, western Lake Superior tributaries	40
Harlow, 1966[b]	Raisin River, Michigan	60
Owen, 1965[b]	Ontario agricultural watershed	33
Hardy, 1966[b]	Upstream areas of Big Muddy River system, Illinois	110
Hrbacek (1965)	Two reservoirs in Czechoslovakia	21

[a] As reported by Mackenthun (1965)

[b] Private communication to Verduin, plus papers presented at the Ninth Conference on Great Lakes Research, Chicago, 1966.

Treatment Methods for Animal Wastes

As pointed out in the previous sections, the control measures most likely to be employed for disposing of animal manures and feedlot runoff are diversion, retention ponds, confinement, proper location, evaporation ponds, and land disposal of manures. Many other methods of disposal have been employed in field and laboratory experiments. These are described in detail in the mass flow model presented in Section VI on animal waste disposal (Figure 20).

Excluding the control methods listed above, and the more sophisticated techniques of drying, incineration, and composting, the most frequently used method of disposing of manures and runoff has been through variations of the simple technique of stabilization pond disposal. Many of the variations of stabilization ponds have been employed, such as multistage ponds, aerobic systems, anaerobic, and facultative ponds. The control of oxygen consuming constituents has been satisfactory with the majority of the pond applications. However, the ability of any of the conventional biological treatment schemes to remove phosphorus is limited, and one of the most effective methods of removing phosphorus is the proper application of manures to the land. Land application does not serve as a complete method of removing phosphorus; however, the amounts removed as the leachate seeps through the soil is quite significant, and if runoff from land applications is controlled, a very significant proportion of the phosphorus will be removed.

Land Disposal--

Minshall et al. (1970) reported that up to 20 percent of N, 13 percent of P, and 33 percent of K nutrients may be lost from manure applied on frozen ground where conditions favor maximum early spring runoff. Nutrient losses from surface runoff from plots having manure applied in the summer and incorporated into the soil were less than from check plots that received no manure. If manure is spread on unfrozen ground and incorporated into the soil, little water pollution should result from manure disposal. Minshall et al. (1970) results are summarized in Table 33.

Humenik (1972) has shown essentially 100 percent phosphate removal from swine waste lagoon effluent applied to Norfolk sandy loam soil lysimeters at a rate of 2.54 cm per week. The lysimeters were loaded at this rate for approximately five months, and the phosphate-phosphorus concentrations applied ranged between 2.2 to 20.6 mg/l with the majority of the loadings having a concentration greater than 9.8 mg/l of phosphate-phosphorus.

Liquid dairy manure was applied at rates of 0.5 and 2.0 cm per week to lysimeters filled with Cecil sandy clay loam soil for a period of approximately three months (Humenik, 1972). Phosphate-phosphorus concentrations of the liquid manure ranged from 6.4 to 30.0 mg/l, and the leachate from the lysimeter contained less than 0.007 mg/l of phosphorus for both loading rates.

Table 33. NUTRIENT LOSSES FROM LANCASTER, WISCONSIN, PLOTS ON JANUARY 23 AND 24, 1967 FROM SNOWMELT AND RAINS[a] (MINSHALL ET AL., 1970)

Jan 23 and Jan 24 A.M. Snowmelt and 0.5 in. Rainfall						Jan 24 P.M. 0.75 in. Rainfall			
Plot number (1)	Type of manure and time applied (2)	Runoff in inches (3)	Losses, in pounds per acre			Runoff in inches (7)	Losses, in pounds per acre		
			Total N (4)	Total P (5)	Soluble K (6)		Total N (8)	Total P (9)	Soluble K (10)
3	None	1.103	0.89	0.17	1.63	0.681	0.57	0.14	1.28
7	Average	1.000	0.93	0.12	1.78	0.850	0.30	0.13	0.68
		1.032	0.91	0.15	1.71	0.770	0.44	0.14	0.98
1	Fresh	0.456	0.46	0.06	0.93	0.858	16.53	2.31	3.34
6	January	0.814	0.55	0.08	1.79	0.620	17.93	2.01	5.20
	Average	0.635	0.51	0.07	1.36	0.739	17.23	2.16	4.27
2	Fermented	0.871	0.64	0.16	1.02	0.808	1.44	0.22	1.97
5	May	1.074	1.42	0.16	2.00	0.602	0.68	0.13	0.72
	Average	0.973	1.03	0.16	1.51	0.705	1.06	0.18	1.35
4	Liquid	1.384	0.77	0.20	3.07	0.643	0.49	0.13	0.95
8	May	1.160	0.70	0.18	0.50	0.808	0.32	0.11	1.70
	Average	1.272	0.74	0.19	1.79	0.726	0.41	0.12	1.46
Average 2, 3, 4, 5, 6, 7, 8		1.099	0.90	0.17	1.67	0.733	0.63	0.14	1.23
Average 1 and 6		0.635	0.51	0.07	1.36	0.739	17.23	2.16	4.27
Ratio 1 and 6/others							27 x 17.5	15 x 6.2	3.5 x 3.8
Percentage of applied manure							17.5	6.2	3.8

[a] Manure at the rate of 15 tons per acre was applied to plots 1 and 6 shortly before this rain. Pounds per acre nutrient values applied, from Table 1, N = 96, P = 32.8 and K = 86.5.

Wells et al. (1970) reported removals of constituents other than phosphorus from cattle feedlot runoff when applied to lysimeters containing 30 inches of soil growing various crops. The results are summarized in Table 34. Based upon the results reported by Humenik (1972) and several other investigators (Utah State University, 1969) showing retention of phosphorus by soils from irrigation waters, it is very likely that excellent phosphorus removal would be obtained with any type animal waste or runoff when applied to the soil mantle.

Biological Treatment of Animal Wastes--

Hart and Turner (1965) performed a series of anaerobic lagoon studies with poultry manures and found phosphorus removals to range from 16 to 65 percent; however, effluents contained high concentrations of phosphorus (> 50 mg/l). Phosphorus removal did not appear to be directly related to the loading rate, but the lowest and highest percentage removals were related inversely to the loading rate.

Humenik (1972) reported average phosphate removal by swine waste secondary lagoons to vary from 15 to 34 percent. Values for the reduction in the primary lagoons were not reported. The phosphate-phosphorus concentration in the secondary effluent was greater than 8.2 mg/l.

Studies of lagoon and oxidation ditch treatment of swine wastes indicate that these treatment methods do not produce an effluent that can be discharged directly to a water course (Townshend et al., 1969). Treatment of swine waste with lagoons designed for a mean hydraulic retention time of 6 and 12 months yielded supernatants with phosphorus concentrations

Table 34. AVERAGE CONCENTRATIONS OF POLLUTANTS IN RUNOFF BEFORE AND AFTER PERCOLATION THROUGH 30 INCHES OF SOIL GROWING CROPS AS SHOWN (WELLS ET AL., 1970)

Pollutant	Concentration In Runoff	Concentration Percolating Through		
		Cotton	Grain Sorghum	Midland Bermudagrass
pH	6.85	7.9	8.03	8.0
BOD mg/l	4100	20	19	13
COD mg/l	9500	386	474	250
NH_3 mg/l	423	0	4	0
ORG-N mg/l	67	2	19	0
NO_3 mg/l	40	573	105	787
T.S. mg/l	11,770	4634	10,520	2551
V.S. mg/l	6223	1252	1104	1440
S.S. mg/l	322	164	260	150

of 0.43, 20, and 28 mg/l, respectively. Oxidation ditch treatment of similar wastes produced supernatant phosphorus concentrations of less than 3 mg/l for a mean hydraulic retention time of two months and 584 mg/l where a six months hydraulic retention time was employed. Difficulty was experienced in separating the solids from the oxidation ditch mixed liquor.

Many studies report laboratory and field studies of anaerobic digestion and lagoon treatment of various animal wastes; however, other than the one specifically referred to above, phosphorus removal data are unavailable except for chemical treatment studies (Clark, 1965; Edwards and Robinson, 1969; Hart and Turner, 1965; Loehr, 1967, 1971; Loehr and Agnew, 1967; Okey et al., 1969; Townshend et al., 1970). The chemical treatment removals of phosphorus from animal wastes are comparable with the results reported for sewage treatment. Phosphorus concentrations of less than 0.16 mg/l can be obtained; however, it is very unlikely that the agricultural industry can afford to install these costly treatment schemes.

Most of the animal waste treatment studies utilizing biological methods have not studied phosphorus removal, probably because of the relatively small (less than 25 percent) removals obtained in biological treatment of domestic wastewaters. The few studies mentioned above indicate that the control of phosphorus discharges to the environment are unlikely to be controlled by "conventional" biological processes such as lagoons and digestors.

Animal Waste Phosphorus Discharge Control Strategy

The above summary of the characteristics and treatability of animal wastes and runoff from animal feedlots indicates the wide variability in both the characteristics and performance of treatment facilities. It is also shown that the impact on the water quality caused by animal wastes is due largely to the periodic slug discharges of pollutants that reach a waterway. Because of this slug discharge characteristic, in all probability it will be easier and most economical to control by a combination of the methods porposed by Loehr (1972). A number of feedlot runoff control measures were proposed, such as diversion, retention ponds, confinement, proper location, use of evaporation ponds, and land disposal of the excess liquid and accumulated solid matter. Under certain environmental conditions all of the above methods can be easily adapted to fit a particular situation and control water pollution from feedlot runoff.

It appears that the expense of using conventional waste treatment techniques for feedlot runoff and animal waste will be unnecessary because of the availability of the above mentioned techniques that are relatively unsophisticated and inexpensive. The application of one or all of the proposed techniques for controlling feedlot runoff will vary with the rainfall amount and frequency, geography, and rainfall patterns for a particular area. Several states are considering, or have adopted, legislation for design rainfall criteria. Perhaps the key to controlling feedlot and animal waste pollution is in the selection of the location of the feedlot. Most of the problems that have occurred in the past could easily be avoided had the feedlots been located in areas that were suitable for feedlots. Having located a feedlot properly, land for disposal would also have been available, and the potential for pollution would have been reduced considerably with just these two considerations. Another factor probably as significant as proper location is the number of waste management alternatives that are made available to a feedlot operator. Usually, it does not cost any more to include several alternatives for waste control during the initial construction phase.

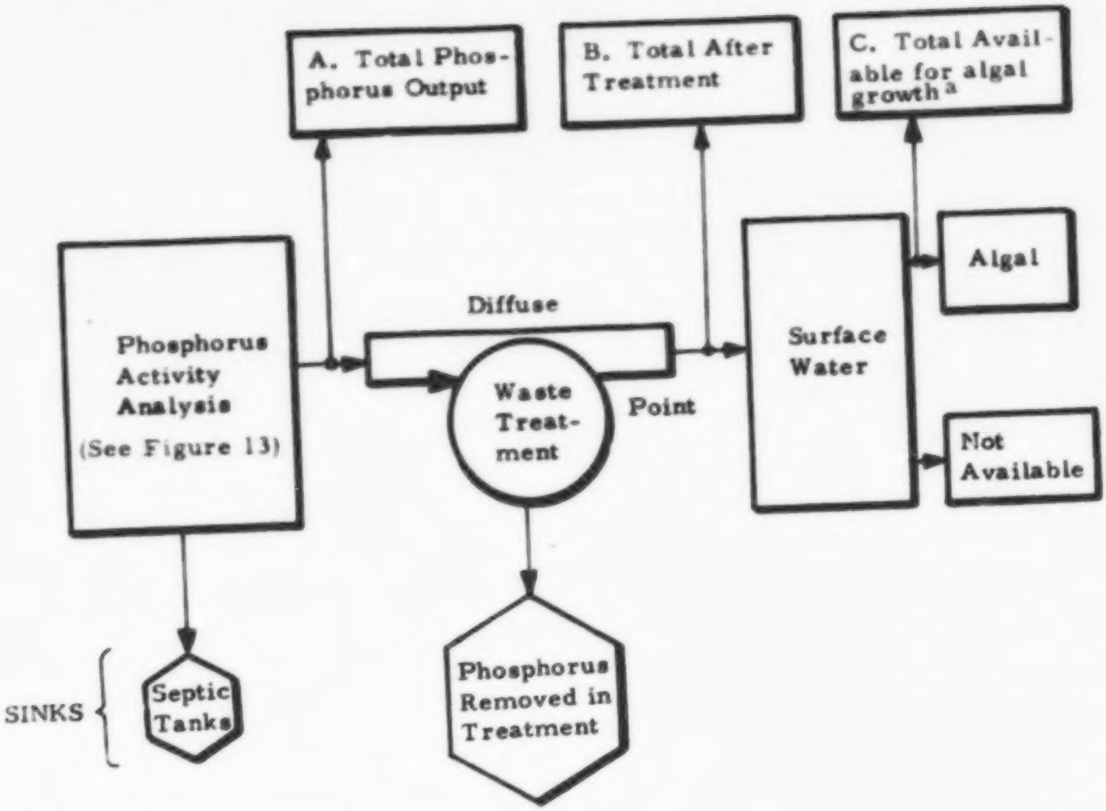
In brief, it appears that the control of animal manures can most easily be handled by relatively unsophisticated and inexpensive techniques. It also appears that the agricultural industry is incapable of absorbing the costs of conventional waste treatment at this time. The costs for nutrient stripping are very high for agricultural wastes and exceed the costs reported for sewage treatment processes. Therefore, wherever possible, the location of feedlots should be such that the old reliable method of confinement and land disposal can be employed.

SECTION VI

PHOSPHORUS ACTIVITY ANALYSIS AND THE MASS FLOW MODEL OVERVIEW

In order to have a system which could be analyzed from the point of view of phosphorus control, a simple program was developed for the major phosphorus-using activities and natural sources (Appendix C).

The program utilized simple input information and then calculated phosphorus output according to different activities. This basic approach is summarized in Figure 18. Some of these activities are further affected by various types of treatments or distributions based on whether wastes are directly discharged or enter treatment plants. The total of all the activities is calculated, as well as the total after treatment, or that portion of the phosphorus which actually enters the surface water; finally, the total of the fraction which enters the surface waters and is actually available for algal growth is calculated. Calculation of eutrophication effects due to phosphorus addition to surface waters is based on two loading rates (total after treatment, and total available for algal growth) because of the uncertainty of the defined relationship between nutrient loading rate and eutrophication. (See Vollenweider, 1968, and Section IV, this report.)


A. Total Phosphorus Output
B. Total After Treatment
C. Total Available for algal growth [a]
Phosphorus Activity Analysis (See Figure 13)
Diffuse
Waste Treatment
Point
Surface Water
Algal
Not Available
SINKS
Septic Tanks
Phosphorus Removed in Treatment

[a] Based on Figure 11 where:

Eutrophication = f(B)

Eutrophication = f(C)

Figure 18. Primary calculated outputs from the phosphorus mass flow model. The subroutines are listed as the different phosphorus-using activities in Figure 13.

The overall scope of phosphorus input to surface waters is outlined in Figure 13. This figure shows the defined phosphorus inputs, whether minor or major, which would be typical for any particular basin of interest and includes those inputs which are of cultural importance as well as those which would occur naturally. These activities or inputs, then, all contribute phosphorus to surface waters in varying degrees. These activities are discussed in relation to this computer program. At the same time, particular literature which relates to the program are referenced. The described inputs have been classified into several major categories, and discussion of these categories in a general way is made in this section of the report. The actual definition of the parameters and how they operate in the input program are defined following this section according to a classification based on methods of control.

PHOSPHORUS USING ACTIVITIES AND METHODS OF CONTROL

The use of phosphorus in various industrial, agricultural, and domestic activities plus natural inputs of phosphorus all contribute to surface water phosphorus content. For each of the major defined activities (Figure 13), appropriate and reasonable control points can be devised at the supply and demand side of the activity as well as for the technological and treatment side of the activity. These controls can be categorized and will be discussed in detail in Section VII. The costs of instituting the controls will be obtained where appropriate. In this way a cost-effectiveness relationship can be defined.

The analysis of the phosphorus inputs to a particular receiving water will be based on particular subroutines and/or numbers obtained from the literature for those particular inputs. These will be based on average values imputed to various activities. For example, (1) domestic wastes phosphorus loadings will be based on a per capita basis; (2) industrial wastes will be based on particular industrial uses; (3) natural inputs, fertilizer runoff, pesticides, and mining wastes will be related to activities placed on an area basis; and (4) animal wastes solid wastes will be on a per capita basis. Thus, for a given subbasin the input of information based on per capita and area estimates of the different activities, will provide an input in terms of mass of material per unit time. This will be coupled to the receiving water eutrophication model as developed in Section IV (Figure 11).

Specific subsections correspond to the subroutine and main program of the phosphorus input program. They have been grouped for discussion purposes into the four following classifications:

1. Minor Diffuse Sources are controllable for other reasons, not very important in terms of percentage of the whole, or not economically controllable.
2. Controllable Diffuse Sources include all sources not described in the first section.
3. Minor Point Sources are controllable for other reasons, not very important in terms of percentage of the whole, or not economically controllable.
4. Controllable Point Sources include all sources not described in the third section.

Although the subsections do not include every possible source of phosphorus, they are undoubtedly more detailed than necessary except for specific situations. This will become evident in the analysis of the results. However, the individual subsections are all included to complete the description of phosphorus input to surface waters and allow a more complete analysis of control strategy. The following sections contain a brief outline and definition of the various parts of the program. The program goes through a series of subroutines described as follows in the order of their appearance in the program to determine the various inputs and then calculate outputs. The upper case words in parentheses refer to parameters in the actual program (see Appendix C). Input values, typical output, and units of the values are in Appendix D. Internal variables will be described only in the text. The actual values (often rough approximations) utilized will be referenced where possible; arbitrary estimates had to be made in the absence of concrete information.

MINOR DIFFUSE SOURCES

The first subroutine (PEST) concerns organophosphate pesticides and the output (OPOUT) is a function of the area (cm^2) of fertilized agriculture (FACRE) in the basin multiplied by a factor (OPFAC, (0.408×10^{-6})):

$$\text{OPOUT} = (0.11)(\text{OPFAC})(\text{FACRE}),\ \text{g/yr} \qquad (10)$$

The factor (OPFAC) is the proportion where pesticides are used (two-thirds) of the total area of fertilized agriculture in the USA (9.7×10^{15} cm^2, Water Resources Council, 1968) divided into the total annual pounds of organophosphate pesticides consumed (36 million kg/yr, Table 8) multiplied by a factor (0.11) which relates the phosphate content to the weight of organophosphate pesticide.

The next subroutine (MINST) is concerned with runoff phosphorus from mining activities that are not associated with phosphorus mining. Thus, strip mining and mine tailings will produce a higher runoff of phosphorus than any other kind of watershed. This output (XMOUT) is a function of the area of strip mines and tailings (XMACRE), the annual precipitation rate (PRATE), the concentration (XMCONC) in the runoff water (estimated to be 0.5 mg P/l), and the ratio (XMFAC) of the runoff water to the total precipitation (assumed to be 0.5):

$$\text{XMOUT} = (\text{XMACRE})(\text{PRATE})(\text{XMCONC})(\text{XMFAC}),\ \text{g/yr} \qquad (11)$$

The next subroutine (SOLWST) concerns solid waste disposal; the phosphorus output from solid waste disposal (SWOUT) is related to the mean annual precipitation (PRATE), the surface area (SACRE) of the landfill, open dump, etc., the concentration of phosphorus in landfill runoff (SCONC) and a runoff factor:

$$\text{SWOUT} = (\text{SACRE})(\text{PRATE})(\text{SCONC})(\text{PRATE}/\text{PRATE} + 25),\ \text{g/yr} \qquad (12)$$

The runoff factor is calculated using a first order-zero order type equation to provide a maximum rate of runoff when the surface becomes saturated. This equation is similar to one derived by Enderlin and Markowitz (1962); it was assumed that their soil-vegetation-permeability, etc., factor could safely be ignored. The runoff factor is obtained using a ratio of the annual precipitation rate divided by the annual precipitation rate, PRATE plus 25 cm/yr, the half maximum value for runoff from solid waste disposal sites. The concentration of phosphorus in the runoff water (SCONC) from landfills is calculated to be 1 mg/l, and represents an estimate obtained from a study performed on runoff from Clear Lake, California (Silvey, 1970). This subroutine provides a very small input in terms of total phosphorus and its output can be easily treated for other reasons (BOD removal, etc.).

The next subroutine (RFALL) is concerned with direct rainfall onto surface waters in the basin; thus, the area of surface waters in the basin (WACRE), the rainfall phosphorus concentration (RAIN) which as determined by Weibel et al. (1969) is 0.08 mg/l, and the mean annual precipitation (PRATE), provides a relationship to estimate the phosphorus entering the streams directly (RAFO):

$$\text{RAFO} = (\text{RAIN})(\text{WACRE})(\text{PRATE}),\ \text{g/yr} \tag{13}$$

Rainfall phosphorus concentrations are quite variable and this parameter should be changed to suit local conditions where it constitutes a significant source (Lee, 1972; Tyler and Uttormark, 1972).

CONTROLLABLE DIFFUSE SOURCES

This subroutine (URBOFF) is concerned with urban runoff and the listed values have been obtained from Weibel et al. (1969). The output (UOUT) is related to the developed urban area (UACRE), the annual precipitation (PRATE), the concentration in urban runoff (UCONC) of 0.36 mg/l phosphorus, and a factor relating runoff to precipitation (UFAC) which is 0.37 (Weibel et al., 1969):

$$UOUT = (UACRE)(PRATE)(UCONC)(UFAC) \tag{14}$$

The next subroutine (NATIN) concerns runoff from natural watersheds and developed, managed forest, and grazing land watersheds. What is done in this case is to determine a runoff rate per unit area (F) which involves the annual precipitation (PRATE), the concentration in runoff from natural watersheds (XNCONC), and a first order-zero order type runoff relationship obtained as follows: The ratio of annual precipitation rate (PRATE) divided by annual precipitation rate plus 10 cm/yr yields a factor which is related to the saturation of the watershed soil:

$$F = (PRATE)(XNCONC)(PRATE/PRATE + 10) \tag{15}$$

After the runoff rate has been obtained, it is multiplied by the area of the particular kind of watershed and a given unit factor (FXD). Because all outputs are related to the phosphate concentration from a natural watershed, the unit factor is 1 for natural watershed areas. Evidence from several investigators (McGauhey et al., 1971, and Likens et al., 1964) indicates that developed watersheds produce about twice as much phosphorus runoff as natural watersheds; the factor (FXD) is 2 for developed watersheds. For managed forests, the factor (FXF) is 1.5, and for grazing lands (FXG) the factor is 1.5. These latter two rather crude factor estimates are based on estimates obtained from Cooper (1969). These outputs (XNAT, XDEV, XFOR, XGRA) are all summed up to produce the total estimate of watershed runoff (XNOUT) as follows:

$$\begin{aligned} XNAT &= (F)(XNACRE) \\ XDEV &= (F)(FXD)(XDACRE) \\ XFOR &= (F)(FXF)(XFACRE) \\ XGRA &= (F)(FXG)(GACRE) \end{aligned} \qquad (16)$$

$$XNOUT = XNAT + XDEV + XFOR + XGRA \qquad (17)$$

Areas of natural watershed (XNACRE), developed watershed (XDACRE), managed forest (XFACRE), and grazing lands (GACRE) can be estimated from planning agency reports (e.g., U.S. Water Resources Council, 1968).

One of the most important controllable diffuse source subroutines (FRTLZR) concerns the application of fertilizer to farmlands. The following program is based on a soil-plant model (Figure 19) described by Jurinak (1973). The model distributes phosphorus into various phases and then phosphorus enters surface waters as a result of runoff and erosion. An annual estimate of fertilization rate in kg P/ha is obtained (FERT). This annual estimate is related to plant growth and uptake of phosphorus using a first order-zero order equation where the maximum value constant is 9 kg/ha year and the half maximum value is 20 kg/ha. Thus, plant uptake (PLA) is calculated as follows:

$$PLA = 9(FERT)/(20 + FERT), \text{ kg/ha} \qquad (18)$$

The remaining fertilizer (DS) is then calculated by subtracting the plant direct uptake of fertilizer from the total applied (FERT - PLA). Then that difference is incremented to the previous level of solid phase phosphorus in the soil for a unit area 15 cm deep (SLDPH):

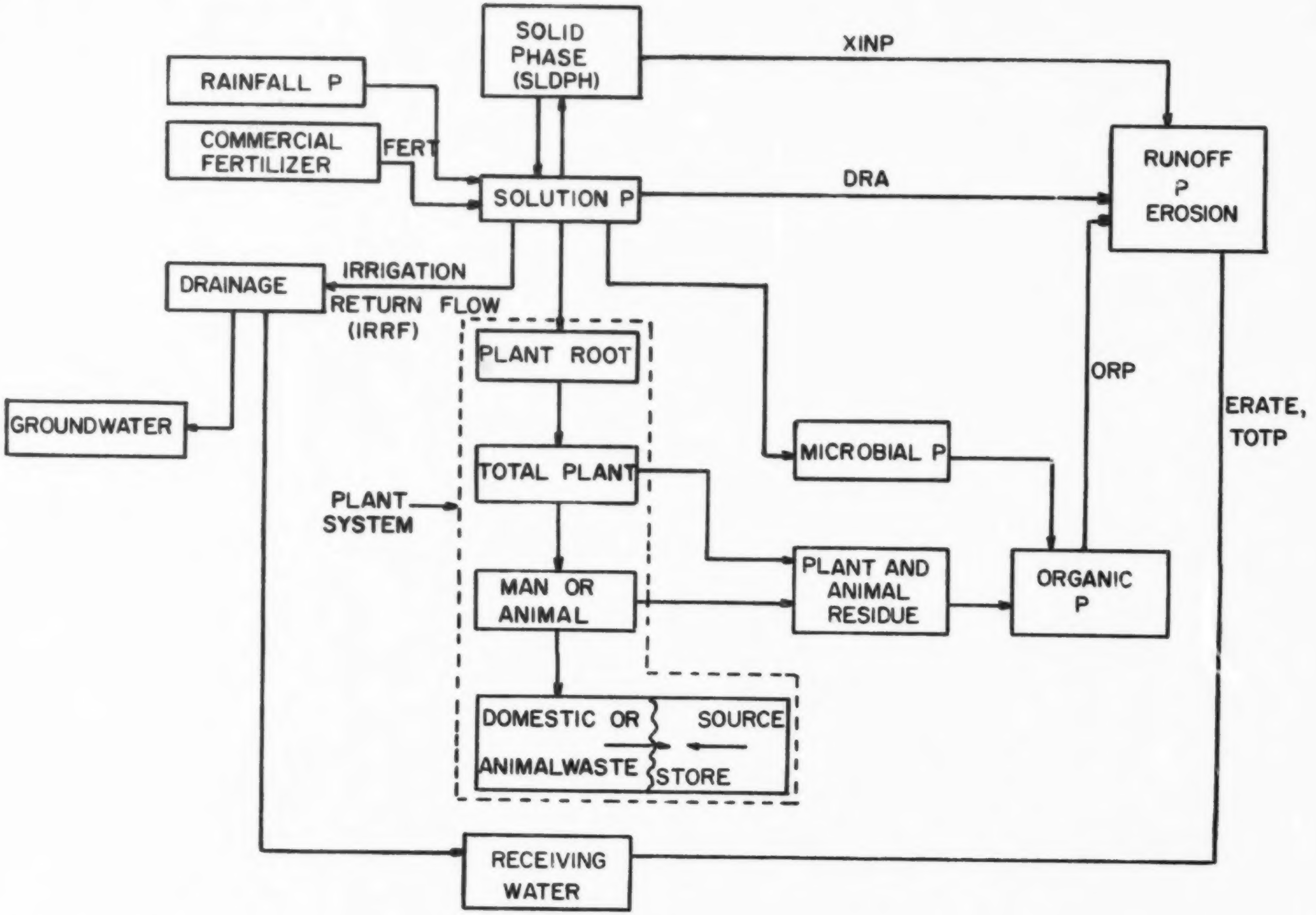

SOLID PHASE (SLDPH)
RAINFALL P
COMMERCIAL FERTILIZER
FERT
SOLUTION P
XINP
DRA
RUNOFF P EROSION
DRAINAGE
IRRIGATION RETURN FLOW (IRRF)
GROUNDWATER
PLANT ROOT
TOTAL PLANT
MAN OR ANIMAL
DOMESTIC OR ANIMALWASTE
SOURCE
STORE
PLANT SYSTEM
MICROBIAL P
PLANT AND ANIMAL RESIDUE
ORGANIC P
ORP
ERATE, TOTP
RECEIVING WATER

Figure 19. Diagram of the phosphorus distribution used to program the effect of phosphorus fertilizer application on the phosphorus load of surface waters. (Note: Results were based on net phosphorus transfer.)

$$SLDPH = SLDPH + (DS/CF), \text{ ppm} \quad (19)$$

These values are expressed in parts per million (CF = 2.27 and converts kg/ha to ppm). Then the remaining plant uptake (SA) is calculated based on this solid phase phosphorus and is again a first order-zero order equation having the maximum relative factor of 12.7 ppm and the half maximum value of 330 ppm. Thus, the total plant uptake of phosphorus (PLA) is obtained as follows:

$$PLA = PLA + SA, \text{ kg/ha} \quad (20)$$

in which

$$SA = (12.7(SLDPH)/(330 + SLDPH))(CF), \text{ kg/ha} \quad (21)$$

Then the solid phase portion is recalculated, subtracting uptake by the plant and adding back a portion of the plant which is considered to have either decayed on an annual basis or been replaced as roots or litter:

$$SLDPH = SLDPH - (SA/CF) + 0.25(PLA/CF), \text{ ppm} \quad (22)$$

The decay, roots, and litter portion is considered to be about 25 percent of the mass of the plant. This factor (0.25) will vary considerably with crop type, cultivation practice, etc., but it has minimal effect on the outcome and only is used as a reasonable estimate.

The erosion model is the Universal Soil Loss Equation; values can be estimated from Handbook 282 of the U.S. Department of Agriculture (Wischmeier, 1968). This function relates: Erosivity (R), which is a factor relating rainfall rate and intensity to erosion rate; the K (SK) factor which concerns the variation in the soils and properties of erosion which primarily are a function of soil type; the cropping management factor (C); a practice factor (P) which concerns such things as contouring, terracing, strip cropping, or other practices which reduce erosive potential of runoff; and a length-slope (L-S) relationship.

The length-slope relationship is as follows (Wischmeier and Smith, 1965): The mean length of slope times the quantity $0.0076 + 0.0053S + 0.00075S^2$ in which S is the percent slope for a particular basin cropland system. For this model three grades of land slope were utilized: From 0-1 percent, from 1-5 percent, and 5-10 percent. A mean slope within each grade of 0.5 percent, 3 percent, and 7.5 percent was used providing slope effects values of 0.01044, 0.03025, and 0.08954, respectively. Mean length of slope was estimated to be 400 feet for the 0.5 percent slope (FL1), 150 feet for the 3 percent slope (FL2), and 80 feet for the 7.5 percent slope (FL3). The proportion of lands which fall within each grade of slope (FA1, FA2, FA3) are estimated and a summation of the proportion for the three grades equals 1. Because the Universal Soil Loss Equation provides data as tons/acre, a factor (0.00224) is used to convert to g/cm^2; the conversion factor applies to the overall erosion rate.

Thus, for each general type of land within a basin an overall constant (Z) is estimated:

$$Z = (R)(SK)(C)(P)(0.00224) \tag{23}$$

Then the erosion rate for each type of land (A1, A2, A3) in terms of the length-slope relationship and the relative quantities of land having a particular length-slope is obtained:

$$\begin{aligned} A1 &= (FA1)(FL1)(Z)(0.01044) \\ A2 &= (FA2)(FL2)(Z)(0.03025) \\ A3 &= (FA3)(FL3)(Z)(0.08954) \end{aligned} \qquad (24)$$

The overall erosion rate (ERATE) is the sum of the above type-constant erosion rates:

$$ERATE = A1 + A2 + A3,\ g/cm^2 \cdot yr \qquad (25)$$

The several phases of phosphorus contributions are calculated: 2.5 percent of the soil is assumed to be organic matter and thus 2.5 percent of the eroded material contains organic phosphorus (A):

$$A = 0.025(ERATE),\ g/cm^2 \cdot yr \qquad (26)$$

The fraction of this organic material that is organic phosphorus is estimated to be 0.0056; thus, organic phosphorus in runoff from agricultural lands (ORP) is:

$$ORP = (A)(0.0056),\ g\ P/cm^2 \cdot yr \qquad (27)$$

The remainder (97.5 percent) of the eroded material contains the inorganic phosphorus tied up with soils:

$$B = ERATE - A,\ g/cm^2 \cdot yr \qquad (28)$$

The inorganic phosphorus (XINP) is equal to the quantity of nonorganic soil eroded times the solid-phase phosphorus per unit area of 15 cm depth:

$$XINP = (B)(SLDPH/1{,}000{,}000),\ g\ P/cm^2 \cdot yr \qquad (29)$$

Soluble phosphorus is considered to be a constant value per unit area as long as sufficient solid-phase phosphorus is present in the soil; this is usually the case for most cropped soils. This constant value (DRA) is estimated to be 1.2 μg P/cm^2·yr.

Thus, the total phosphorus output from fertilized soils (cropland) is equal to the organic phosphorus in the eroded soil (ORP) plus the inorganic phosphorus in the eroded soil (XINP) plus the soluble orthophosphate (DRA) runoff. When the area of the cropland (FACRE) is considered, the total output (TOTP) from the basin can be calculated as follows:

$$\mathrm{TOTP} = (\mathrm{ORP} + \mathrm{XINP} + \mathrm{DRA})(\mathrm{FACRE}),\ \mathrm{g\ P/cm^2} \qquad (30)$$

Outputs from the individual sources are also determined. The erosion rate (ERATE, g/cm^2·yr) is also an output; it can be converted simply to metric tons/ha·yr by multiplying by 100.

MINOR POINT SOURCES

This subroutine (IRRRF) is concerned with irrigation return flows; although this is a rather minor point source input of phosphorus, it is included for completeness. It becomes a point source through channelization, tail waters, and drain collection systems. Because treatment of irrigation return flows for other reasons (e.g., salinity and nitrate removal) may be necessary (Brown, 1971), it is also possible to remove phosphorus, though this is usually a minimal part of the problems associated with return flows. Irrigation return flow phosphorus output (RFOUT) is calculated as follows:

$$\mathrm{RFOUT} = (\mathrm{FLOW})(\mathrm{RFONC}),\ \mathrm{g/cm^2} \qquad (31)$$

in which the quantity of irrigation return flow is FLOW, and the concentration in the return flow is RFCONC containing 20 μg/l orthophosphate phosphorus (Biggar and Corey, 1969).

The next subroutine (RIVR) is concerned with the possibility that a river flowing into the basin of interest represents activities far removed from that particular basin. This subroutine merely calculates the phosphorus input from that river (RIVER) as a function of the phosphorus concentration in the river (RCONC) and the mean annual flow of the river (RFLO):

$$\text{RIVER} = (\text{RCONC})(\text{RFLO}) \tag{32}$$

This is considered an uncontrollable phosphorus input to the surface water of interest.

CONTROLLABLE POINT SOURCES

This first subroutine (DOWST) is a calculation of input of phosphorus via waste products of human populations (DOUT). DOUT is considered a function of the human population (CAP), the grams of phosphorus excreted per year by the average human (795.6 g/yr, estimated from Vollenweider, 1968), and a factor (SFAC 2(1)) which relates the amount of sewered to the total population:

$$\text{DOUT} = (\text{CAP})(795.6)(\text{SFAC } 2(1)) \tag{33}$$

It is assumed that garbage disposal wastes, cooking water, etc., can contribute phosphorus but that it is included in this total. No attempt has been made to estimate that contribution separately. The septic tank portion of phosphorus (SEPD) is also estimated and it is the non-sewered population. As discussed further on, this quantity is considered as a "sink," i.e., it does not enter the surface waters. However, in unsuitable soils, etc., and when septic tanks fail as many do in their lifetime, phosphorus will enter the surface waters.

Also, a proportion (DFAC) of the sewered population directly discharges into surface water and this value (DOUTD) is calculated. The amount of sewered which goes to the treatment plant then is added into the domestic sewage total value discussed below.

The detergent subroutine (DTERG) is used twice, for domestic use (denoted by (1)) and for industrial detergent use (denoted by (2)), because of the method used for calculating detergent phosphorus contributions. First, washing products were classified in four groups: High phosphate (HP) detergents, low phosphate (LP) detergents, no phosphate (NP) detergents, and soaps (SO). In addition, estimates of the fraction of detergents used by the population were made for each particular classification of detergent (PHP, PLP, PNP, PSO, respectively). The mean estimated phosphorus concentrations (PLBHP, PLBLP, PLBNP, PLBSO, respectively, P/g detergent) and the mean relative use of the detergent (PHPPC, PLPPC, PNPPC, PSOPC) was calculated for each classification. Then the total detergent phosphorus contribution (D) is calculated by summing for each of the four classifications the products of (1) phosphorus concentration in the particular detergent; (2) detergent phosphorus concentration; and (3) detergent use per capita. Then this is multiplied by the population (CAP):

$$\begin{aligned} D = {} & ((PHP)(PHPPC)(PLBHP) + (PLP)(PLPPC)(PLBLP) \\ & + (PNP)(PNPPC)(PLBND) + (PSO)(PSOPC)(PLBSO)) \\ & (CAP)(SFAC) \end{aligned} \tag{34}$$

This total is multiplied further by the septic tank factor (SFAC) described above in the human wastes subroutine. The discharge of domestic detergent into septic tanks (a "sink"), direct discharge of detergent into the river, and discharge into the sewer system is based on the same factors as for the human wastes subroutine.

The industrial detergent and cleansers phosphorus use is based on the same method of detergent type classification, concentration, and uses. However, the population of industrial users has been determined in a different way. This population is calculated based on the industrial consumptive use of water and the total amount of phosphorus used in detergent manufacture minus the amount of phosphorus utilized by the domestic population. (It is estimated that 28 percent of the total phosphorus in detergent manufacture is used industrially.) This value is corrected to the population in the basin. Further explanation of the industrial consumptive use of water and per capita relationships is contained in the subroutines on other industrial use of phosphorus in the paragraph below. Appropriate adjustments of the distribution for the discharge of industrial detergents to septic tanks, sewers, or direct discharges are made in the subroutine for industrial detergent phosphorus also.

The next subroutine (INDUST) is concerned with industrial usage of phosphorus excluding detergents and cleansers. Several major types of phosphorus uses in industry are considered.

A common industrial use of phosphorus is in water softening. This use (DWSOUT) was estimated by multiplying the population (CAP) by the output of phosphorus from this activity (DWSFLO) and by a consumption factor related to population (DMCONC) obtained for each particular basin from data supplied by the Water Resources Council of the U.S. (1968):

$$\text{DWSOUT} = (\text{DWSFLO})(\text{DMCONC})(\text{CAP}) \tag{35}$$

The Council has described 21 particular basins for which water uses have been determined. The consumption factor (DMCONC) was obtained by assuming consumptive industrial use of water was related to the use of water softening compounds (also of industrial detergents as described and of miscellaneous phosphorus uses). Then for each basin this value is divided by the total population of the basin. The total use of water softening compounds containing phosphorus can be estimated (Lewis, 1970). It is estimated to be 38,000 tons per year; that value is unchanged from 1958 because it is estimated that although water softener use in industry has increased, nonphosphate products have represented the increase in use. This number is divided by the annual consumptive use of water and multiplied by the consumptive use per capita for each of the 21 basins.

Another industrial output of phosphorus is a summation of many industrial activities. These are called miscellaneous industrial phosphorus output. They are analyzed in the same way as for water softening. A calculated output (DMOUT) based on industrial consumptive use (DMFLO) is multiplied by the consumption factor (DMCONC) and population (CAP) of the basin:

$$\text{DMOUT} = (\text{DMFLO})(\text{DMCONC})(\text{CAP}) \tag{36}$$

Metal finishing (pickling or metal etching) wastes often contain large amounts of phosphates because of the use of phosphoric acid in this process. These are calculated on an estimated use of phosphoric acid in this industry (DMTL). It is best to actually determine this phosphorus use for a particular basin.

Two specialized industrial outputs are from food wastes and from phosphorus mining activities. Food wastes phosphorus are calculated as coming from loss of food materials (DFWT) and are based on a loss factor (DFUSE) of about 10 percent of the foods reaching the processor and on a phosphorus concentration (DFCONC) of 1 percent in the food. This output (DFOUT) is considered to be entirely organic phosphorus:

$$\mathrm{DFOUT} = (\mathrm{DFWT})(\mathrm{DFCONC})(\mathrm{DFUSE}) \tag{37}$$

Phosphorus mining activities are fairly well controlled, primarily because they are a point source and other pollutants associated with output from these activities such as fluorides have attracted considerable regulatory attention. The output from these activities (DPMOUT) is calculated as being the concentration in the mining waste that enters the surface water (DPMIN) multiplied by the flow of wastewater or spilled wastes (DPMFLO):

$$\mathrm{DPMOUT} = (\mathrm{DPMIN})(\mathrm{DPMFLO}) \tag{38}$$

Generally, phosphorus mining companies are fairly careful with their liquid wastes and usually these kinds of wastes meet standards (which may or may not be too permissive) or are released only under spill type conditions. Strict enforcement or higher standards for pond storage building codes might prevent this kind of spill relationship and eliminate this source of phosphorus. These five outputs from the industrial subroutine plus industrial detergent use constitute the total phosphorus output from industry.

The next subroutine (ANMAN) is output from animal wastes and merely calculates the animal waste phosphorus based on a per capita output of phosphorus on an annual basis and the population number for each of four groups of animals. The phosphorus output per animal is derived from the data reviewed in Section V of this report. These values are 3,564 g/yr (PCOW) from typical cattle, 92.4 g P/yr (PCHIC) from chickens, 888 g P/yr (PPIGS) from pigs, and 456 g P/yr (PSHEP) from sheep and goats. Note that horses are included in the cattle output. However, they are a small number (about 3 percent; Vollenweider, 1968) in comparison to the total cattle population. Thus, the total cattle output for a basin is merely the phosphorus output times the number (COWS) of cattle and horses and similarly for the other domestic animals:

$$\mathrm{COUT} = (\mathrm{PCOW})(\mathrm{COWS}) \qquad (39)$$

Animal waste treatment is based on the flow chart shown in Figure 20. In this flow chart, there are various possible means of treatment considered. The input variables and symbols for the various distributions are shown in the flow chart. The values of phosphorus output from a particular animal group is calculated based on the particular distribution of treatment methods used in the basin. By substituting certain other kinds of treatment one can obtain an estimate of the effect as related to that particular treatment on phosphorus release into surface waters.

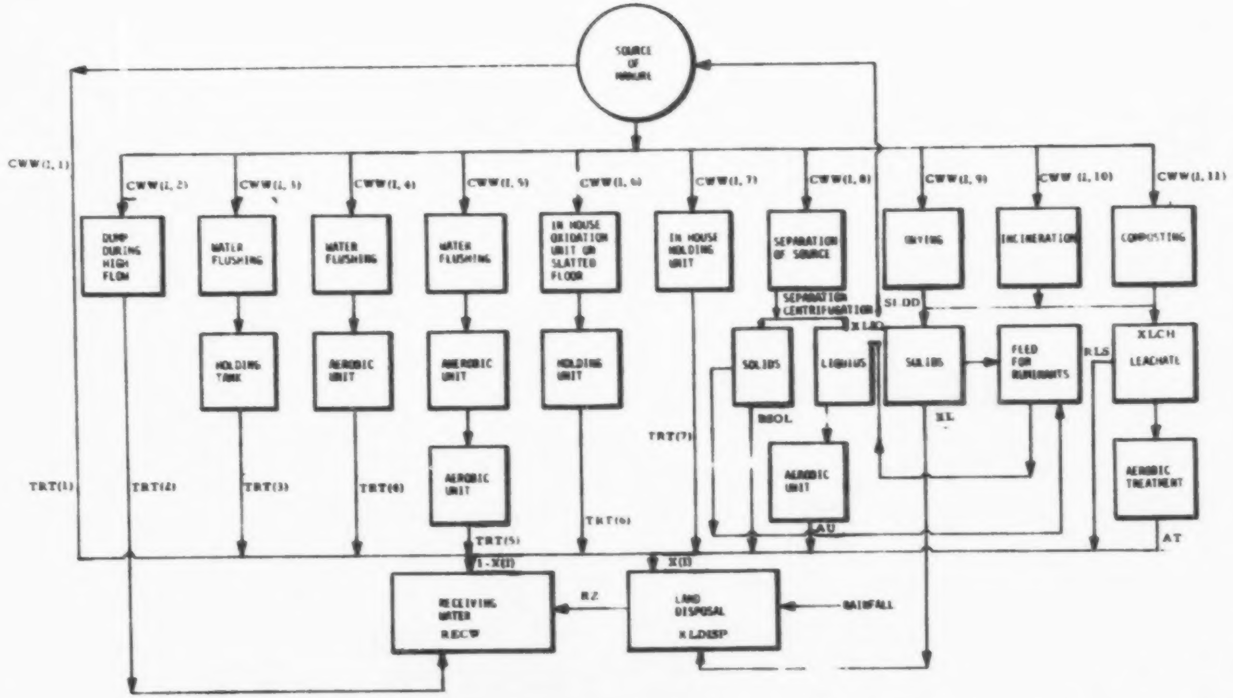

SOURCE OF MANURE
CWW(I, 1)
CWW(I, 2)
CWW(I, 3)
CWW(I, 4)
CWW(I, 5)
CWW(I, 6)
CWW(I, 7)
CWW(I, 8)
CWW(I, 9)
CWW (I, 10)
CWW(I, 11)
DUMP DURING HIGH FLOW
WATER FLUSHING
WATER FLUSHING
WATER FLUSHING
IN HOUSE OXIDATION UNIT OR SLATTED FLOOR
IN HOUSE HOLDING UNIT
SEPARATION OF SOURCE
DRYING
INCINERATION
COMPOSTING
HOLDING TANK
AEROBIC UNIT
ANAEROBIC UNIT
HOLDING UNIT
SEPARATION CENTRIFUGATION
SOLIDS
LIQUIDS
SOLIDS
FEED FOR RUMINANTS
LEACHATE
XLCH
RLS
SI DD
XLIQ
SSOL
XL
AEROBIC UNIT
AEROBIC UNIT
AEROBIC TREATMENT
AU
AT
TRT(1)
TRT(2)
TRT(3)
TRT(4)
TRT(5)
TRT(6)
TRT(7)
1-X(I)
X(I)
RECEIVING WATER
RECW
RZ
LAND DISPOSAL
XLDISP
RAINFALL

Figure 20. Treatment methods that have been applied to animal manures and feedlot runoff.

The subroutine asks certain questions about the different treatments and then calculates whether the treatment results in land disposal or disposal directly to receiving waters. The model calculates the amount disposed on the land (XLDISP) and then calculates the amount disposed into receiving water by summing the direct discharge into receiving water (RECW) with the amount disposed on land multiplied by a factor (RZ) of 0.05 (estimated by Vollenweider, 1968) for each particular group of animals. Biggar and Corey (1969) estimate a loss of about 5 percent of applied manure to frozen ground in the Lake Mendota drainage system, so Vollenweider's value represents an upper limit. This results in a final summation for each kind of animal (ANOUT for cattle, chickens, pigs, and sheep) for the amount of phosphorus entering the surface water:

$$ANOUT = ((RECW) + (RZ)(XLDISP))RJAN \qquad (40)$$

The fraction of animal waste phosphorus considered available for algal growth (RJAN) was estimated as 0.5.

MODEL REPRESENTING PHOSPHORUS REMOVAL PROCESSES

Subroutine TREAT (see Appendix C for details) has been developed to represent the sewage treatment plant component of the Phosphorus Mass Flow Model. From a set of alternatives, the subroutine selects the least cost system which will provide adequate phosphorus removal.

Following are descriptions of the terms used in the subroutine:

Input Terms

P: phosphorus concentration in the influent stream (mg/l)

Q: flow on influent stream

NTYPE: the total number of treatment process alternatives to be considered (integer)

ITYPE (I): identification number of Ith individual treatment system alternative to be considered (integer)

POMAX: maximum allowable phosphorus concentration in the effluent stream (mg/l)

Output Terms

ITYPES: identification number of the least cost treatment system required to provide an effluent concentration of POMAX (integer)

a. if no treatment is required, ITYPES = 17 to flag the main program
b. if degree of treatment required cannot be provided by any of the system alternatives, ITYPES = 16 to flag the main program

PO: phosphorus concentration in the effluent from system ITYPES (mg/l)

COST: cost of treatment system ITYPES ($/year)

Internal Terms

QMGD: flow of influent stream in mgd

QMGY: flow of influent stream in million gallons per year

XCOST (I): cost of providing treatment by ITYPE (I) ($/year)

XPO (I): phosphorus concentration in effluent from ITYPE (I) (mg/l)

I: index of current system alternatives (integer)

PMIN1-
PMIN10: minimum phosphorus concentration obtainable in effluent from current system (mg/l)

ITEST: indicator to flag situation where degree of treatment required cannot be provided by any of the systems alternatives (integer)

A flow diagram of the subroutine is shown in Figure 21. Values for P, Q, NTYPE, and POMAX are input from the main program. If the influent phosphorus concentration (P) is less than the maximum allowable (POMAX) in the effluent, no treatment is required; ITYPES is set equal to 17 and control is returned to the main program. Otherwise all of the alternatives systems are checked one by one to determine: (1) If the system currently being considered can provide adequate treatment (i. e., is a feasible process); (2) the cost of providing this treatment XCOST (I); and (3) the effluent phosphorus concentrations from this system, XPO (I). The annual cost of each feasible system is checked against the annual cost of the previous feasible system and the minimum is retained as COST. After all alternatives have been considered, values for ITYPES, PO, and COST are returned to the main program. If no feasible system exists, ITYPES is set equal to 16.

TREATMENT SYSTEM ALTERNATIVES

Figure 22 is a schematic diagram showing the unit processes associated with common phosphorus removal systems. Because all of the possible combinations of unit processes depicted in the figure do not represent practical treatment systems and because some practical combinations have similar removal and cost characteristics, selected unit processes

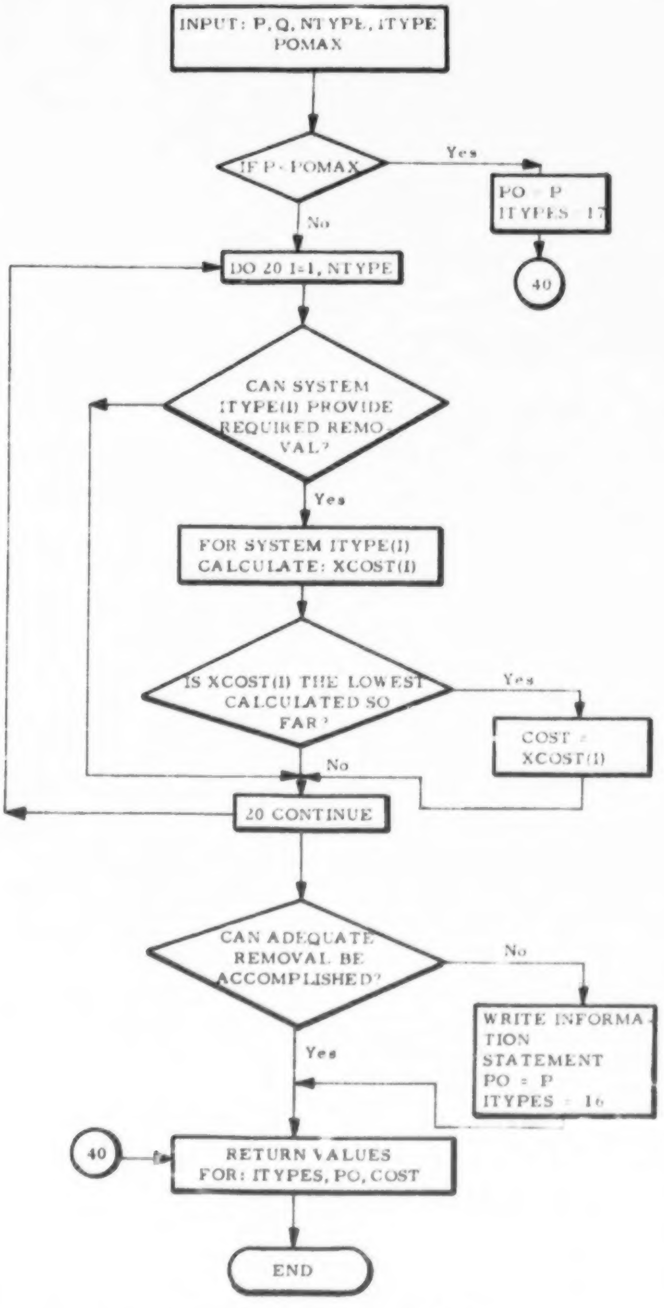

INPUT: P, Q, NTYPE, ITYPE
POMAX
IF P < POMAX
Yes
PO = P
ITYPES = 17
40
No
DO 20 I=1, NTYPE
CAN SYSTEM ITYPE(I) PROVIDE REQUIRED REMOVAL?
Yes
FOR SYSTEM ITYPE(I) CALCULATE: XCOST(I)
IS XCOST(I) THE LOWEST CALCULATED SO FAR?
Yes
COST = XCOST(I)
No
20 CONTINUE
CAN ADEQUATE REMOVAL BE ACCOMPLISHED?
No
WRITE INFORMATION STATEMENT
PO = P
ITYPES = 16
Yes
40
RETURN VALUES FOR: ITYPES, PO, COST
END

Figure 21. Flow diagram for subroutine TREAT.

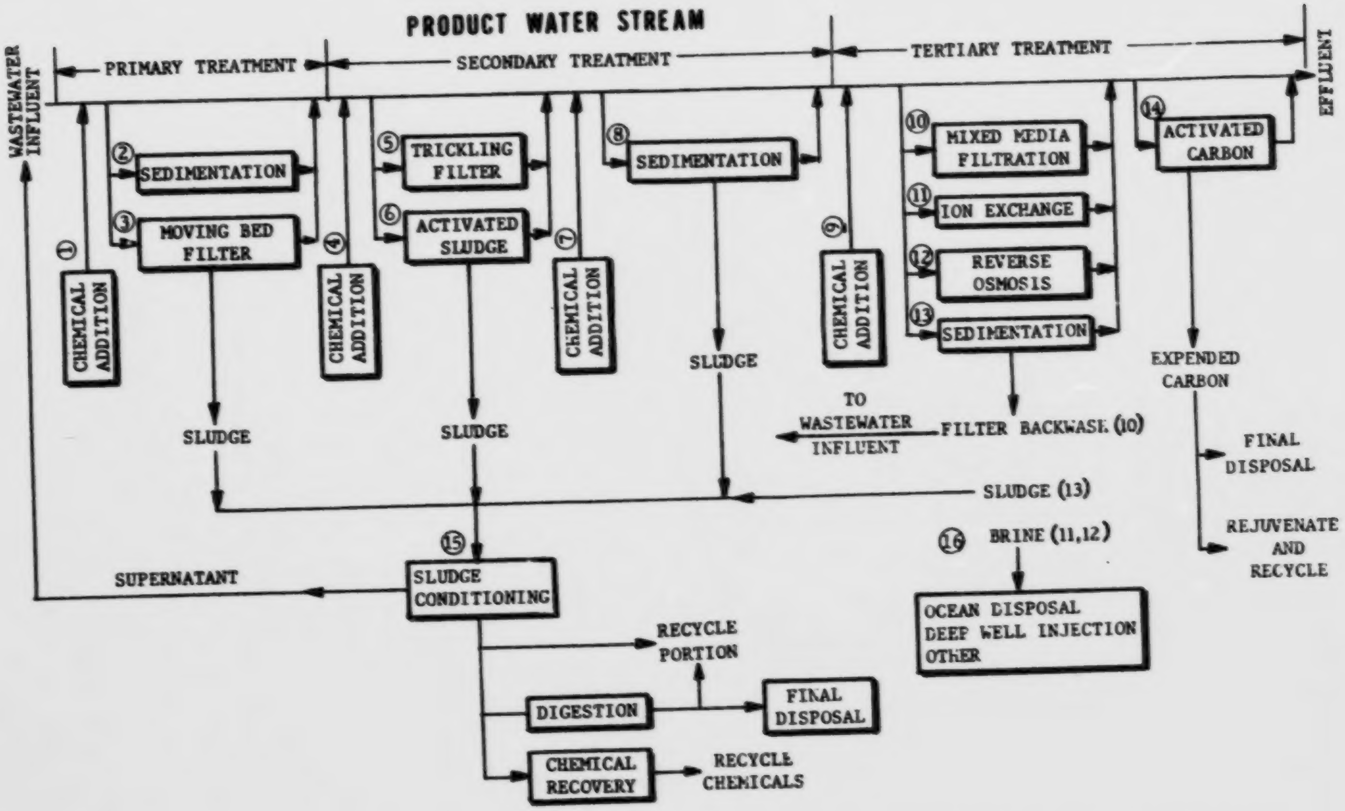

PRODUCT WATER STREAM
PRIMARY TREATMENT
SECONDARY TREATMENT
TERTIARY TREATMENT
WASTEWATER INFLUENT
EFFLUENT
① CHEMICAL ADDITION
② SEDIMENTATION
③ MOVING BED FILTER
④ CHEMICAL ADDITION
⑤ TRICKLING FILTER
⑥ ACTIVATED SLUDGE
⑦ CHEMICAL ADDITION
⑧ SEDIMENTATION
⑨ CHEMICAL ADDITION
⑩ MIXED MEDIA FILTRATION
⑪ ION EXCHANGE
⑫ REVERSE OSMOSIS
⑬ SEDIMENTATION
⑭ ACTIVATED CARBON
SLUDGE
SLUDGE
SLUDGE
TO WASTEWATER INFLUENT
FILTER BACKWASH (10)
SLUDGE (13)
EXPENDED CARBON
FINAL DISPOSAL
REJUVENATE AND RECYCLE
⑮ SLUDGE CONDITIONING
SUPERNATANT
RECYCLE PORTION
DIGESTION
FINAL DISPOSAL
CHEMICAL RECOVERY
RECYCLE CHEMICALS
⑯ BRINE (11,12)
OCEAN DISPOSAL
DEEP WELL INJECTION
OTHER

Figure 22. Schematic diagram showing unit processes associated with common phosphorus removal systems.

have been grouped into four process systems which represent the general range of removal efficiencies and costs. The four treatment systems which have been selected for the example runs are as follows:

1. Chemical coagulation at an existing activated sludge plant. No additional clarification or sludge handling costs are included.
2. Tertiary chemical coagulation of secondary effluent.
3. Selective ion exchange. Not including lime disposal.
4. Reverse osmosis. Not including lime disposal.

Costs and removal efficiencies have been taken from data reported in the literature. Because of the wide variability in the data, depending on the location of the facility and the characteristics of the wastewater, the removal levels and cost functions developed in this section are intended only to represent the relative ranges of the systems. For example, phosphorus residuals in the range of about 2 to 0.5 mg/l may be reasonable levels to expect in effluent from chemical coagulation in secondary treatment plants and 0.5 to 0.1 mg/l have been reported for tertiary coagulation followed by mixed media filtration (Jenkins et al., 1971; Culp and Culp, 1971). In order to represent a "typical" plant for the model, the minimum phosphorus level which could be consistently maintained for processes 1 and 2 was set at 1.0 mg/l. All costs have been adjusted to the 1971 ENR Construction Index (base year 1967 = 100). A capital recovery factor of 0.08 was used in the calculations.

1. Chemical coagulation at an existing activated sludge plant. (Zenz and Pivnicka, 1969; EPA, 1971e; Jenkins et al., 1971; Directo et al., 1972) Functions are based on precipitation with Fe (III).

a. Unit process combinations (from Figure 22):

2, 4, 5, 7, 8; 2, 4, 6, 7, 8; 2, 4, 5, 8; 2, 4, 6, 8;
2, 5, 7, 8; 2, 6, 7, 8

b. Minimum concentration which can be obtained by the process = 1.0 mg/l

c. Maximum possible removal 95 percent

d. Chemical cost ($\$_C$) dollars per year (Figure 23):

$$\frac{Fe}{P} = 1.0 \qquad 0\% < \text{removal} < 74\%$$

$$\frac{Fe}{P} = \frac{(\%\ \text{removal}) - 62.0}{12.57} \qquad 74\% < \text{removal} < 95\%$$

$$\$_C = 2.251 * P * QMGY * (\frac{Fe}{P})$$

e. Chemical storage and labor ($\$_L$) dollars per year:

$$X = 73.2 * (\frac{Fe}{P}) * P * QMGD \text{ (lbs feed/day)}$$

$$\$_L = 5600; \qquad 0 < X < 1000$$

$$\$_L = 4800 + 33.6\ X^{0.5935}; \qquad 1000 < X < 6000$$

$$\$_L = 2.065\ X^{0.6792} + 33.62\ X^{0.5935}; \qquad 6000 < X$$

f. Total cost per year:

$\$/\text{year} = \$_C + \$_L$

2. Tertiary chemical coagulation of secondary effluent. (Convery, 1970; EPA, 1971a)

a. Unit process combinations (from Figure 21):

9, 13

b. Minimum concentration which can be obtained by the process = 1.0 mg/l

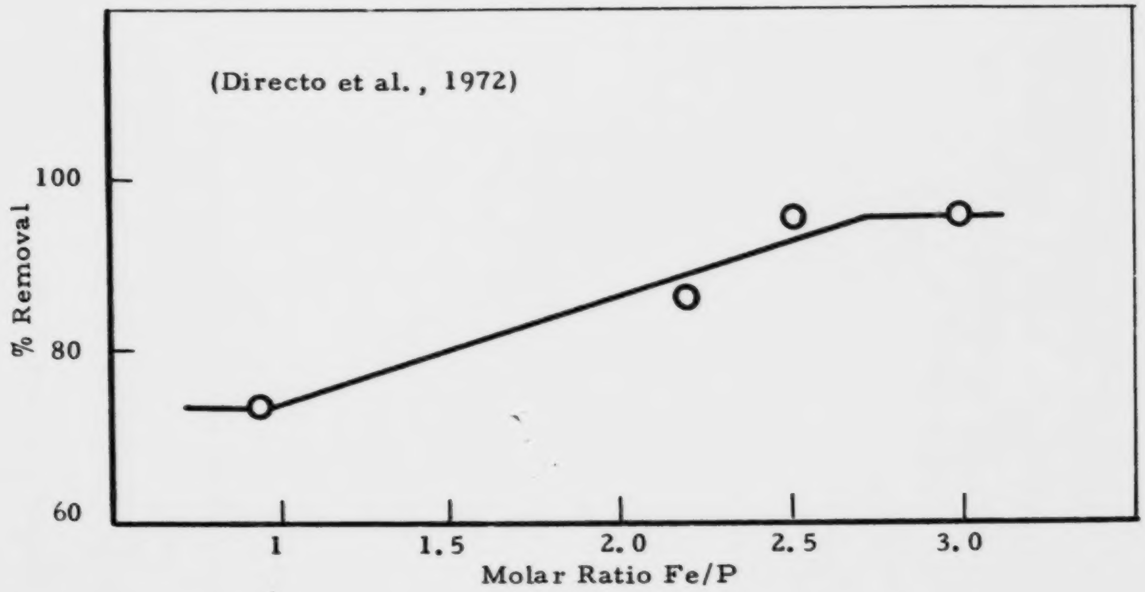


Figure 23. Percent phosphorus removal vs. applied molar ratio Fe/P.

c. Maximum possible removal = 95%

d. Capital costs ($\$_{cap}$) dollars per year (Figure 24):

$$\$_{cap} = 13,600\ \text{mgd}^{0.856}$$

e. Chemical and operating costs:

Same as Process No. 1

f. Total cost in dollars per year = $\$_{cap} + \$_C + \$_L$

3. Selective ion exchange. (EPA, 1970a; EPA, 1971d; Bishop et al., 1972)

a. Unit process combinations (from Figure 21):

11

b. Minimum concentration which can be obtained by the process = 0.5 mg/l

c. Maximum possible removal = 98%

d. Capital costs ($\$_{cap}$) dollars per year (EPA, 1971d):

$$QADJ = QMGD \qquad 0 < P\text{-}PMAX < 10$$

$$QADJ = QMGD*(\frac{P\text{-}PMAX}{10}) \qquad 10 < P\text{-}PMAX$$

$$\$_{cap} = 19,832\ QADJ^{0.920}$$

e. Chemical and operating and maintenance costs (Figure 25) in dollars per year:

$$\$_L = [0.18\ QADJ^{-0.3815} + 0.09\ QADJ^{-0.2245}]*QMGY*1000$$

f. Total cost in dollars per year = $\$_{cap} + \$_L$

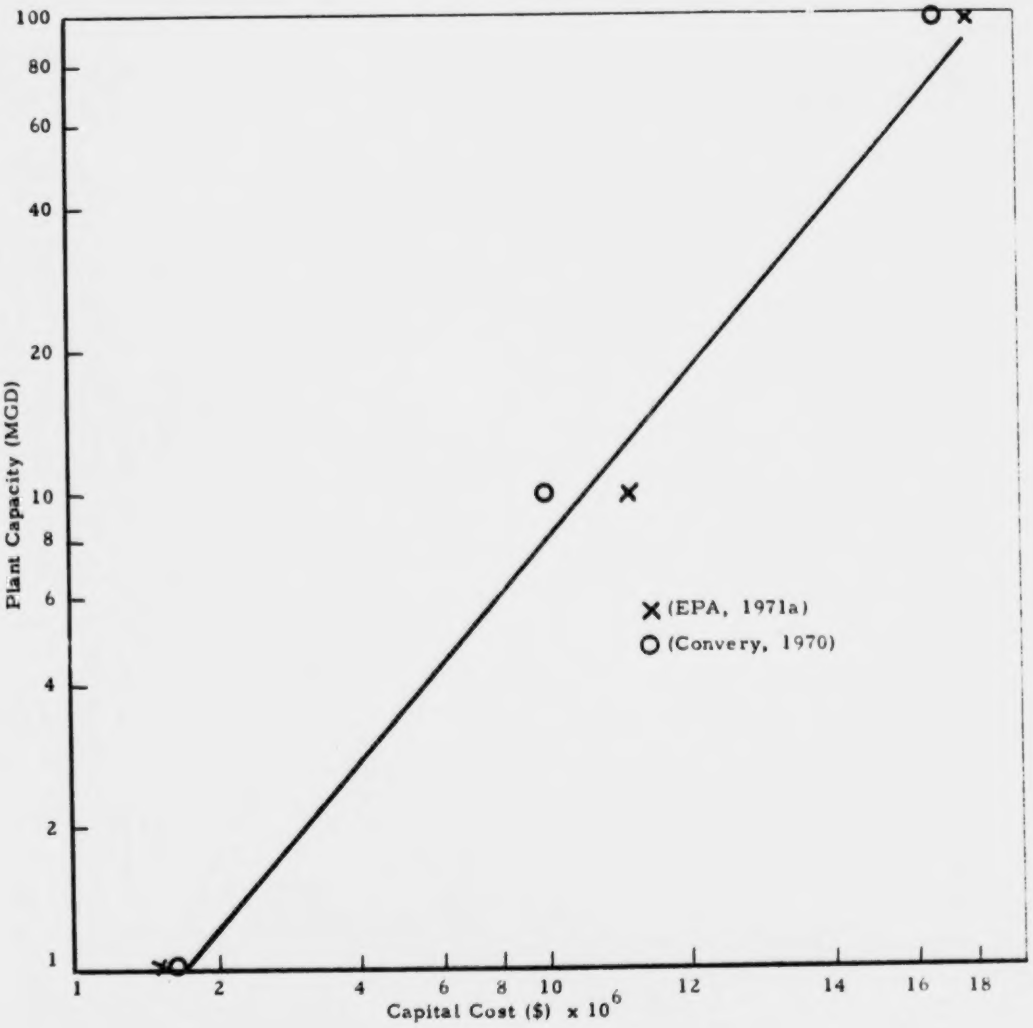


Figure 24. Capital costs for tertiary chemical coagulation.

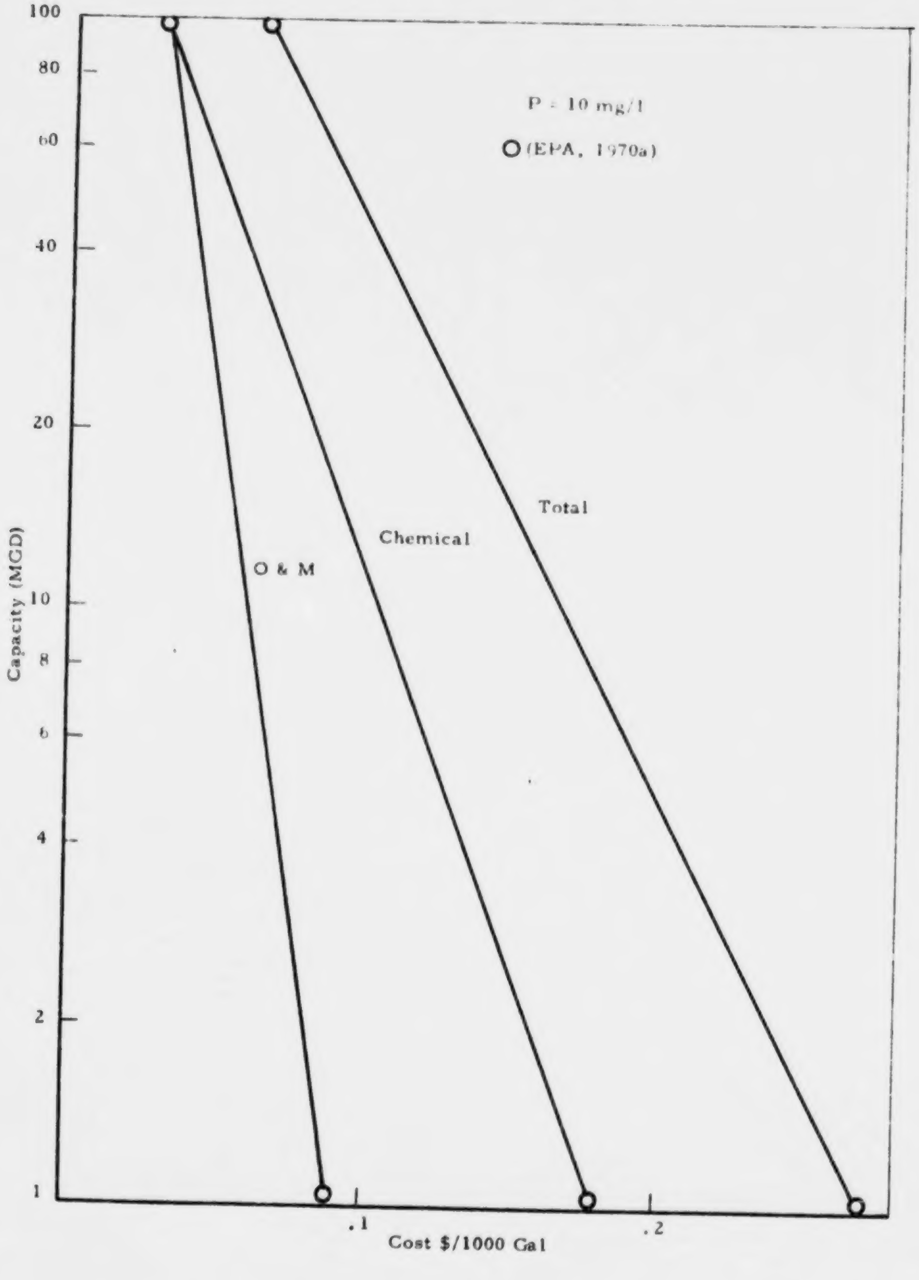


Figure 25. Selective ion exchange.

4. Reverse osmosis. (Besik, 1971; Dodson, 1971; Dryden, 1969; EPA, 1970d; Kerr, 1971)
   a. Unit process combination (from Figure 21):
      12
   b. Minimum concentration which can be obtained by the process = 0.05 mg/l
   c. Maximum possible removal = 99%
   d. Flow recovery = 85%
   e. Blending:

      $$QADJ = QMGD\left(\frac{P - .85\ POMAX}{P}\right)$$

      in which QADJ = amount of flow to be treated
   f. Total cost in dollars per year (Figures 26 and 27):

      $\$ = 0.705 - 0.243 \log_{10} QADJ$ TDS $\doteq$ 1500 to 5000

      $\$ > 0.30$

      $\$ = 1.05\ QADJ^{-0.3132}$ TDS $\doteq$ 35,000

      $\$ > 0.25$

DISTRIBUTION OF SEWERED AND UNSEWERED POINT SOURCE PHOSPHORUS ACTIVITIES AND THEIR TREATMENT AND COSTS

After calculation of all the subroutine phosphorus-using activities and their outputs, further distributions as to direct discharge and/or treatment in-plant or treatment at a municipal treatment plant is evaluated (see Figure 13, Section V, showing distributions). These calculations are performed in the main program (Appendix C).

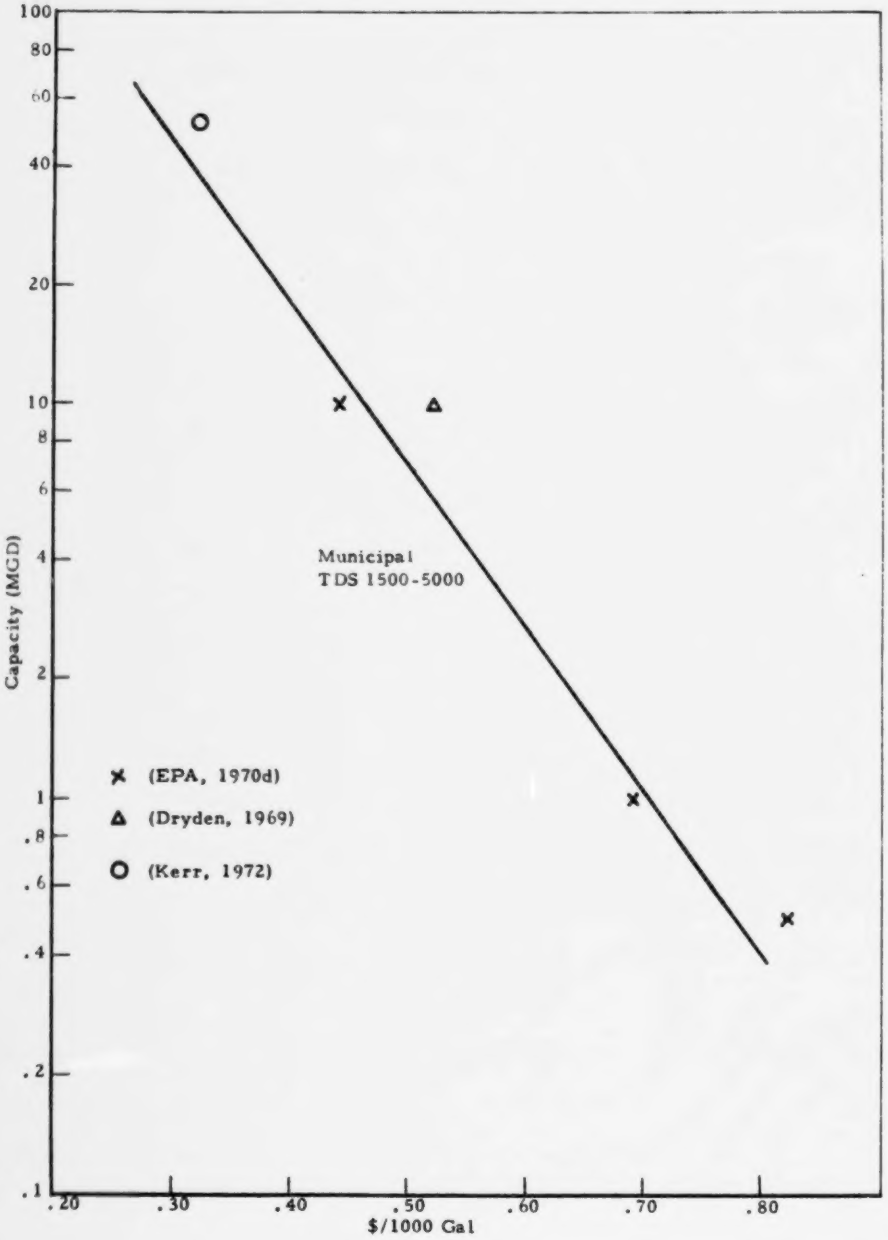


Figure 26. Total costs for reverse osmosis treatment of municipal effluent.

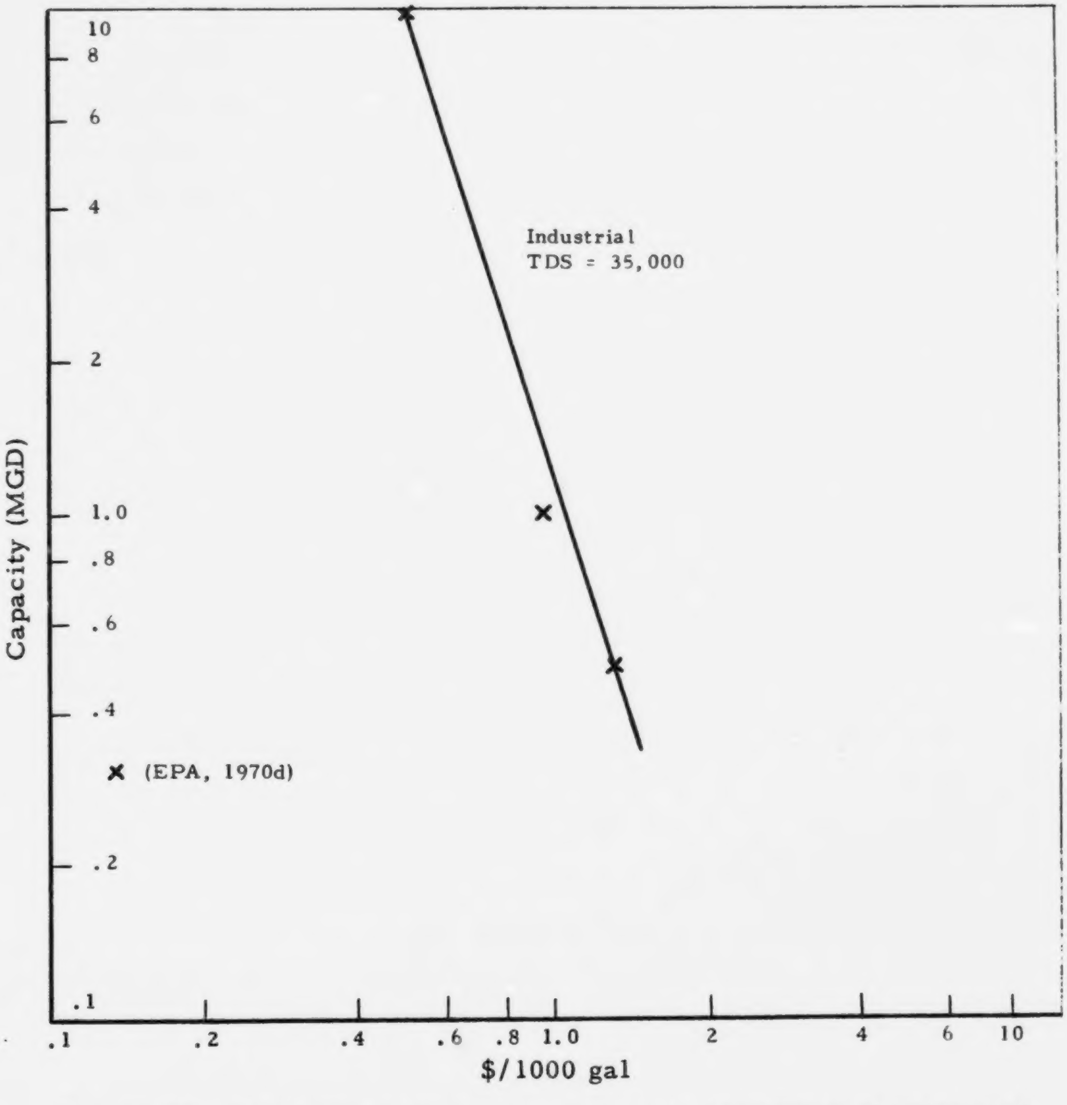


Figure 27. Total costs for reverse osmosis treatment of industrial effluent.

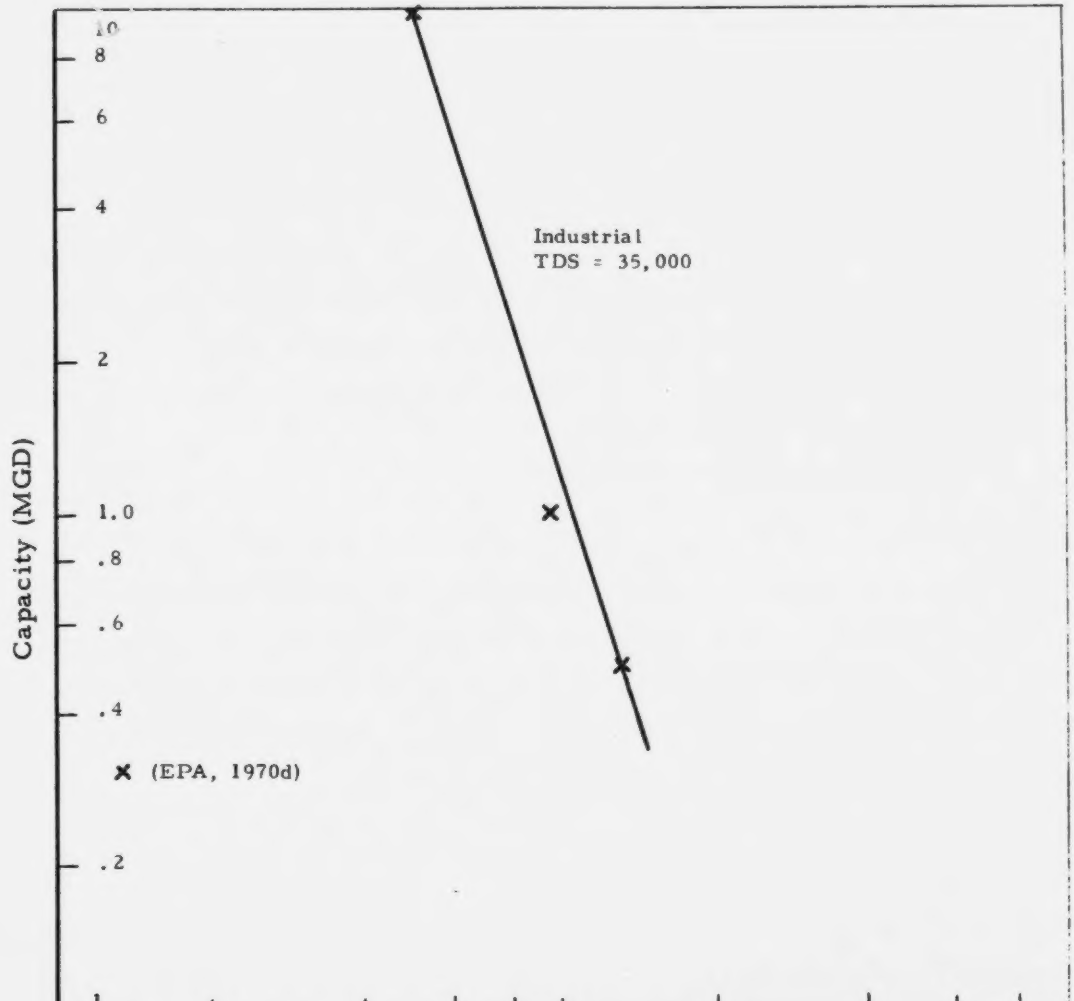


Figure 27. Total costs for reverse osmosis treatment of industrial effluent.

First, urban runoff (UOUT) is distributed to direct discharge or to the domestic treatment plant (SURB) if combined sewers are in use; no provision for overflow of combined sewers is made as this factor is considered in the apportionment between direct discharge and sewering. Phosphorus from industrial and domestic wastes which would overflow from combined sewer overflow are not included in this output because of the complexity of the interrelationships, even though such material can be significant as in Lake Erie (Federal Water Pollution Control Administration, 1968). Also, it is anticipated that problems with combined sewer overflow will be eliminated by EPA enforcement actions. A simple factor indicating the proportion of sewered to total urban runoff is used (FAC1). Thus, unsewered urban waste (USURB) goes directly into the surface water.

Next, the outputs of the industrial waste from detergent use, water softening use and miscellaneous industrial phosphorus uses are distributed. The sum of these outputs (DON) is multiplied by a factor (FAC2) reflecting the sewered portion (SIND). The sewered portion is subtracted from the total to provide the unsewered material (USIND), discharged directly into the surface water; the sewered portion goes into the municipal treatment plant.

Analysis of metal finishing wastes is performed as follows: First, a portion may have the possibility of in-plant treatment. The fraction which is not treated (WALK) is determined by subtracting the total metal finishing waste minus the total output of metal finishing wastes multiplied by a factor (FAC3). The remaining material (BOB) is apportioned to in-plant treatment (subroutine TREAT). The concentration

(CON1) is calculated by dividing the remaining material (BOB) by a flow value (FLO1) which is input data. Then a treatment level is ascribed and in the usual case 80 percent (TT1) removal is required which means that the effluent concentration of phosphorus (POM) from treatment must be 0.2 times the concentration of phosphorus in the influent. Then the treatment subroutine (TREAT) is called. The output from the treatment subroutine (PDS1) in g P/yr is then added to the material which is not treated (POR = WALK + PDS1). Also, a portion of this effluent can be discharged directly to surface water (UPOR) so a sewered portion (SPOR) is obtained by multiplying by a factor (FAC4); these outputs are distributed to direct discharge or to the municipal treatment plant.

Food wastes are treated similarly to metal finishing wastes, i.e., there is in-plant (BILL) and no treatment (GREN) distributed using a factor (FAC5); The concentration (CON2) is calculated by dividing the in-plant portion by flow input data (FLO2); a level of treatment (TT2) required to produce an effluent of a desired phosphorus concentration (POM) is defined; the output from treatment (PDS2) plus the amount not treated in-plant is totaled (CEL) and distributed (1) to the municipal treatment plant (SCEL) by multiplying by a factor (FAC6) and (2) to direct discharge (UCEL) by difference. The output from in-plant treatment of food wastes is considered to be essentially zero because such wastes are biologically treated and require phosphorus additions to make up for the wastes being phosphorus deficient for microbial metabolism.

The amount of phosphorus entering the municipal treatment plant (DOMIN) is the sum of human wastes output (DOUT), domestic detergent use (DTOUT), urban runoff in combined sewers (SURB), industrial use of detergents, water softeners, and miscellaneous uses which enter the sewer system (SIND), and the amount of phosphorus entering sewers from metal finishing (SPOR) and food wastes (SCEL). To determine treatment levels and costs this total (DOMIN) is divided by the flow (FLO6) of all the individual inputs to determine concentration (CON3). This flow is obtained by summing the input flows from metals and food wastes which directly enter sewage ((FLO1)(FAC4), (FLO2)(FAC6)) and the following calculated flows: (1) The domestic flow (FLO3) is based on the product of population (CAP), mean population use of water (100 gal/cap·day), and the proportion of sewered population (SFAC); (2) urban runoff flow (FLO4) is based on runoff as calculated from the urban runoff subroutine, i.e., urban acreage (UACRE) times precipitation rate (PRATE) times the runoff factor (UFAC) times the portion entering the sewer (FAC1) times a conversion factor to liters (0.001); (3) the output from the grouped industrial wastes (FLO5) is considered a function of industrial consumptive use and is calculated by multiplying the population by the factor related to consumptive use for the particular basin (BASF) and the factor related to discharge into the sewer (FAC2).

The program then apportions the total flow (FLO6) at a level of phosphorus removal (TT3), 0, 25, 80, 95, or 99 percent removal, to the various treatment plants in the basin (1, N treatment plants) using a series of factors (FFAC(1), FFAC(N)). Thus, the treatment costs ($/year) and methods are determined according to whether the basin treats the sewage at a single site (to obtain economy of scale) or at many sites. The output (TPMIN) is a summation of all the phsophorus from all the treatment plants. A separate listing of each treatment plant is included specifying the flow (l/year), the influent concentration (mg/l), the effluent concentration (mg/l), actual percent P removed, and the cost ($/year). Also, the values for flow and cost are totaled for the year.

Wastes from phosphorus mining plants are treated similarly to the other industrial wastes except that entering the municipal treatment scheme is not provided. Direct discharge before treatment can occur using a proportion (FAC7) of the total output from phosphorus mining (DPMOUT) as going to the TREAT subroutine (SMIN) and the remainder (UMIN) as direct discharge. The phosphorus concentration entering TREAT (CON4) would be equal to the proportion treated (SMIN) divided by an input flow value (FLO7). The phosphorus effluent from treatment is then PDS4.

SUMMATION OF PHOSPHORUS ENTERING SURFACE WATERS

The activities previously described all produce phosphorus of various forms which enter surface waters. These forms are not all equally available to plant growth and thus are not all of equal importance in their role in causing eutrophication. Also, not all of the activities which produce phosphorus actually result in additions to the surface water of interest. Consequently, several totals are calculated (refer to Figure 18). First, the total for all the phosphorus producing activities is calculated; this total (TOTAL) is the sum of the pesticide output, the strip mines and tailings runoff, total watershed runoff, the fertilized agricultural output, the irrigation return flow output, the output from the four animal groups after treatment, domestic waste output, the domestic detergent use output, the industrial wastes output, the solid waste and urban runoff, phosphorus mining output, direct rainfall on the surface water, whatever river inflow enters the system, and direct release of domestic detergent and human phosphorus outputs. This, then, is the total of all the activities producing phosphorus in the system.

The next total (EFFP) represents the actual amount which is likely to enter the surface water of interest and is composed of the pesticide, strip mine and tailings runoff, total watershed runoff, fertilized agricultural runoff, irrigation return flow, outputs from the four animal groups after treatment, solid wastes, the unsewered urban runoff, unsewered industrial wastes from detergent, miscellaneous, and water softening uses, and unsewered portions of metal finishing wastes and food wastes, plus the output from the municipal treatment plant, the direct rainfall on the water, the untreated mine wastes entering the water, and its unsewered portion plus the river inputs and whatever direct discharges of domestic human and detergent uses which occur.

Because not all of this total is actually considered available to growth of organisms, a further breakdown, called available effluent phosphorus (AEFFP), is totaled. A crude estimation of whether or not the material in question is in the insoluble inorganic or organic form is made to compose this total. Thus, the available phosphorus for plant growth is considered to be the total of the runoff from strip mines and tailings, the inorganic phosphorus portion from the fertilized agriculture output, irrigation return flow, total watershed runoff, a percentage (RJAN) of the total of the animal wastes which enter the surface waters (usually 50 percent), solid wastes runoff, plus direct rainfall onto the surface waters plus the treatment plant effluent (all of which is considered available), the unsewered urban runoff and the unsewered portions of industrial and phosphorus mining activities, one half of the total material entering through any influent river (RAFO), and the unsewered direct discharge of domestic human and detergent phosphorus. These totals represent the areas of interest in regard to minimizing eutrophication. One important point concerning direct discharge of industrial wastes, runoff from mining, and other possibly toxic materials is that cessation of their discharge may remove a toxic factor suppressing algal growth. Such discharges have a double-edged effect: (1) Discharge of phosphorus may be unimportant because of toxicity; and (2) cessation of discharge may increase productivity because of removal of toxic materials.

OUTPUT FROM THE PROGRAM

The output from all of the different activities as described above and the miscellaneous totals and subtotals which are of interest are all printed on a single page (the multiple treatment plant information as described above is listed on a second page) and are listed in Table 35; first, each activity is named and then the quantities of phosphorus: Column 2 lists the amount of phosphorus actually generated in g/year, and then in fractions of the three different totals enumerated just above; the third column is the fraction of TOTAL; the fourth column is the fraction of the material actually entering the surface water (EFFP); and the fifth column is the fraction of material which is assumed to be available (AEFFP).

Table 35. REPRESENTATIVE EXAMPLE OF PROGRAM OUTPUT SHOWING PHOSPHORUS ACTIVITY ANALYSIS, MASS FLOW AND RELATIVE EUTROPHICATION

```
PARAMETER     F L A R 12        AMT (G/YR)        P TOTAL       P EFF        P AEFF        ACCUMULATED  TR PROC         COST

ORGANO PHOS PEST                2791536.00        0.0001        0.0001                     33490432.00
STRIP MINE + TAILING           10750000.00        0.0004        0.0004       0.0005       129000000.00
FERT RUNOFF(SLOP =385.97)    5575672140.16        0.2057        0.2060                  73010560229.12
   EROSION RATE                      0.171
   ORG PHOSPHORUS            1491605998.06        0.0550        0.0556                  17899271986.40
   INORG PHOSPHORUS          4009426141.38        0.1479        0.1496                  54215608242.56
   DRAIN PHOSPHORUS            74640000.00        0.0025        0.0028       0.0038       895680000.00
IRR RETURN FLOW P                 15600.00        0.0000        0.0000       0.0000          187200.00
SOLID WASTE OUT                  832882.88        0.0000        0.0000       0.0000         9994594.59
NAT DEV RUNOFF                862635541.67        0.0318        0.0322       0.0440     10351626500.00
   NATURAL RUNOFF             616333333.33        0.0227        0.0230                   7395999999.92
   DEVELOP RUNOFF              98613333.33        0.0036        0.0037                   1183360000.00
   MAN. FOR. RUNOFF                   0.00        0.0000        0.0000                            0.00
   GRAZING RUNOFF             147688875.00        0.0054        0.0055                   1772266500.00
RAINFALL                     1768160000.02        0.0652        0.0660       0.0902     21217920000.16
RIVER                        3306600000.00        0.1234        0.1220       0.1686     39679200000.00
DOM DIRECT DISCHARGE                  0.00        0.0000        0.0000                            0.00
DOM DET DIRECT DISCH                  0.00        0.0000        0.0000                            0.00
SEWERED DOMESTIC             7956000000.00        0.2935                                95472000000.00
SEW DOM. DET P               2622960000.02        0.0968                                31475520000.16
URBAN RUNOFF                  340238080.00        0.0125                                 4170856960.00
IND OTHER OUT                2062589760.00        0.0761                                24751077120.00
MISC P OUT                   1375625000.00        0.0507                                16507500000.00
WATER SOFTENING               816500000.00        0.0301                                 9798000000.00
METAL FIN OUT                  12000000.00        0.0004                                  144000000.00
FOOD WASTE OUT                   147000.00        0.0000                                    1764000.00
MINING P OUT                          0.00        0.0000                                          0.00
MUN TREAT INFLUENT          12741068100.72        0.4700                                26451264000.00
IND DET + OTHER IND          4266861760.00        0.1574                                51202341120.00
COW MANURE OUT                123888000.00        0.0046                                 1486656000.00
CHICK MANURE OUT              162624000.00        0.0060                                 1951488000.00
PIG MANURE OUT                 63936000.00        0.0024                                  767232000.00
SHEEP MANURE OUT               35978400.00        0.0013                                  431740800.00
IN-PLANT TRT METALS             2400000.00                                                            COAG        15820.75
IN-PLANT TRT FOODS               147000.00                                                            NO TRT          0.00
UNTREATED TOTAL             27107943940.72                                             331397821836.16

COW AFTER TREAT                26985903.60                      0.0010       0.0007       323830843.20
CHICK AFTER TREAT              40725115.20                      0.0015       0.0010       488701382.40
PIG AFTER TREAT                 5357836.80                      0.0002       0.0001        64294041.60
SHEEP AFTER TREAT               7033327.47                      0.0003       0.0002        84399929.64
UNSEWER URB.                  327343795.20                      0.0122       0.0167      3928125542.42
UNSEWER IND.                 2127357380.00                      0.0794       0.1085     25528288560.00
UNTREATED METALS                 820800.00                      0.0000       0.0000         9849600.00
UNTREATED FOODS                   16758.00                      0.0000       0.0000          201096.00
TREAT PLANT EFF             12741068106.72                      0.4753       0.6498    152892817203.20                    0.00
TREAT P MINING EFF                    0.00                      0.0000       0.0000               0.00   NO TRT           0.00
UNTREATED MINING                      0.00                      0.0000       0.0000               0.00
TREATED TOTAL               26804166723.76        0.9893                               327752495232.00

AVAIL TREATED TOTAL         19606991956.18        0.7233        0.7315                 235283903473.20

DOM SEPTIC TANK              1989000000.00                                              23868000000.00
DET SEPTIC TANK               655740000.01                                               7868880000.16

EUTROPHICATION (EFF)               41.3512       53.1911       27.1171      20.0593        13.5585      10.4296         0.3437
EUTROPHICATION (AEFF)              59.5075       38.4955       19.5137      13.2584         9.9173       7.6292         0.1033
```

Table 35. REPRESENTATIVE EXAMPLE OF PROGRAM OUTPUT SHOWING PHOSPHORUS ACTIVITY ANALYSIS, MASS FLOW AND RELATIVE EUTROPHICATION

```
PARAMETER      Y E A R 12        AMT (G/YR)      P TOTAL       P EFF       P AEFF        ACCUMULATED  TR PROC        COST

ORGANO PHOS PEST                  2791536.00      0.0001       0.0001                     33490432.00
STRIP MINE + TAILING             10750000.00      0.0004       0.0004      0.0005        129000000.00
FERT RUNOFF(SLOP =385.97)      5575672140.16      0.2057       0.2090                  73010560229.12
   EROSION RATE                        0.171
   ORG PHOSPHORUS              1491605990.60      0.0555       0.0556                  17899271906.40
   INORG PHOSPHORUS            4009426141.34      0.1479       0.1496                  54215608242.56
   DRAIN PHOSPHORUS               7464000.00      0.0025       0.0028      0.0036         89568000.00
IRR RETURN FLOW P                   15600.00      0.0000       0.0000      0.0000           187200.00
SOLID WASTE OUT                    832882.88      0.0000       0.0000      0.0000          9994594.59
NAT DEV RUNOFF                  862635541.67      0.0316       0.0322      0.0440      10351626500.00
   NATURAL RUNOFF               616333333.33      0.0227       0.0230                   7395999999.92
   DEVELOP RUNOFF                90613333.33      0.0036       0.0037                   1103360000.00
   MAN. FOR. RUNOFF                     0.00      0.0000       0.0000                            0.00
   GRAZING RUNOFF               147688875.00      0.0054       0.0055                   1772266500.00
RAINFALL                       1768160000.07      0.0652       0.0660      0.0902      21217920000.16
RIVER                          3306600000.00      0.1234       0.1220      0.1686      39679200000.00
DOM DIRECT DISCHARGE                    0.00      0.0000       0.0000                            0.00
DOM DET DIRECT DISCH                    0.00      0.0000       0.0000                            0.00
SEWERED DOMESTIC               7956000000.00      0.2945                               95472000000.00
SEW DOM. DET P                 2622960000.02      0.0968                               31475520000.16
URBAN RUNOFF                    348238080.00      0.0128                                4178856960.00
IND DETER OUT                  2062589760.00      0.0761                               24751077120.00
MISC P OUT                     1375625000.00      0.0507                               16507500000.00
WATER SOFTENING                 816500000.00      0.0301                                9798000000.00
METAL FIN OUT                    12000000.00      0.0004                                 144000000.00
FOOD WASTE OUT                     147000.00      0.0000                                   1764000.00
MINING P OUT                            0.00      0.0000                                         0.00
MUN TREAT INFLUENT            12741069106.72      0.4703                               26451264000.00
IND DET + OTHER IND            4266861760.00      0.1574                               51202341120.00
COW MANURE OUT                  123888000.00      0.0046                                1486656000.00
CHICK MANURE OUT                162624000.00      0.0060                                1951488000.00
PIG MANURE OUT                   63936000.00      0.0024                                 767232000.00
SHEEP MANURE OUT                 35978400.00      0.0013                                 431740800.00
IN-PLANT TRT METALS               2400000.00
                                                                                                    COAG         15828.75
IN-PLANT TRT FOODS                 147000.00                                                        NO TRT           0.00
UNTREATED TOTAL               27107943940.72
                                                                                      331397621838.16

COW AFTER TREAT                  26985903.69                   0.0010      0.0007        323830843.20
CHICK AFTER TREAT                40725115.20                   0.0015      0.0010        488701382.40
PIG AFTER TREAT                   5357836.80                   0.0002      0.0001         64294041.60
SHEEP AFTER TREAT                 7033327.47                   0.0003      0.0002         84399929.64
UNSEWER DOM.                    327343795.20                   0.0122      0.0167       3928125542.42
UNSEWER IND.                   2127357380.00                   0.0790      0.1085      25528288560.00
UNTREATED METALS                   820800.00                   0.0000      0.0000           9849600.00
UNTREATED FOODS                     16758.00                   0.0000      0.0000            201096.00
TREAT PLANT EFF               12741069106.72                   0.4753      0.6498     152892817283.20                     0.00
TREAT P MINING EFF                      0.00                   0.0000      0.0000                0.00  NO TRT           0.00
UNTREATED MINING                        0.00                   0.0000      0.0000                0.00
TREATED TOTAL                 25804106723.76      0.9633                              327752495232.00

AVAIL TREATED TOTAL           19606991956.16      0.7233       0.7315                 235283903473.20

DOM SEPTIC TANK                1990000000.00                                           23880000000.00
DET SEPTIC TANK                 655740000.01                                            7868880000.16

EUTROPHICATION (EFF)                 81.3512     53.1911      27.1171     20.0593         13.5505      10.4290        0.3437
EUTROPHICATION (AEFF)                59.5075     38.9355      19.5159     13.2586          9.9174       7.6292        0.1033
```

Reproduced from
best available copy.

The sixth column is an accumulation of the annual output which is summed over a period of 12 years (or any other number). Although only the twelfth year is usually printed, this format allows monthly increments and yearly or greater increments if such information is desired. Not all accumulation will be equal to 12 times the annual phosphorus production by a given activity because some change with time (e. g., the fertilizer subroutine). Also, population, areas of activities, and annual precipitation rate can easily be programmed to change with time but are not in this particular program. The next two columns refer to the treatment subroutine (TREAT). The first of these columns tells whether the treatment is unnecessary (NO TRT), whether no process will produce the desired level of treatment (NO PRO), or if treatment does occur, which of the three particular processes which result in the desired level of phosphorus removal. This column is blank for municipal treatment plant effluent because of the separate listing for possible multiple treatment plants. It is in the separate listing that the specified process for each plant is listed (Table D-5, D-6, and D-7, Appendix D). Then the second of the columns lists the costs of such treatment in dollars/year.

The last calculation made in Table 35 is the evaluation of eutrophication in terms of the phosphorus loading rate, $g/m^2 \cdot yr$. It is calculated (1) by dividing total input to surface waters (EFFP) and the available fraction (AEFFP) in g P/yr by the surface area of the receiving water body (RWACRE) to obtain loading, and (2) solving for "relative eutrophication" as a fraction of loading for lakes of differing mean depth (Figure 11). Arbitrary numerical values for eutrophication have been assigned as follows:

Lake Class	Relative Value
Eutrophic	> 10
Mesotrophic	5-10
Oligotrophic	< 5

The numbers represent a very empirical derivation (Vollenweider, 1968) and give no estimate of the functional relationship between different levels of biostimulation, i. e., the comparison of eutrophic to oligotrophic may indicate a linear, logarithmic, geometric, etc., progression of effects in relation to loading. However, if one assumes plug flow (no mixing), a residence time of one year to calculate the inflow (i. e., the treated total entering the lake, EFFP), and the appropriate mean depth with the area of the lake to calculate the volume, the mean concentration can be estimated (assuming phosphorus behaves conservatively--is not removed); it is the relative eutrophication value. For example, in Table 35 for the 50 m lake, the mean concentration of total phosphorus would be 20.8593 μg/l as P and for available phosphorus 15.2984 μg/l as P.

CASE STUDIES

Initially, a hypothetical lake and basin were constructed to test the computer model. The data for this lake were selected to ensure that (1) the basin contained most of the pertinent activities shown in Figure 13; (2) the lake would be very eutrophic so that many strategies could be applied to the basin; and (3) the system would utilize many numbers and data which would be common to most systems. This last point was done to simplify data requirements for application to actual lake systems.

A summary of the important variable parameters for the three systems utilized in the program lists the values of the parameters and the source of the estimates (Table 36). A complete listing of input values is in Appendix D.

Table 36. IMPORTANT VARIABLE PARAMETERS IN PHOSPHORUS INPUT TO SURFACE WATERS PROGRAM (COMPLETES INPUTS LISTED IN APPENDIX D)

Mnemonic of Parameter	Units	Values of Parameters			Source of Data		
		Hypothetical	Lake Michigan	Lake Erie	Hypothetical	Michigan	Erie
PRATE	cm/yr	50	79	86	1	1	1
FAC1	ratio	1.0	0.943	0.9	4	2	3
FAC2	ratio	0.5	0.06	0.86	4	2	3
FAC3	ratio	0	0	0	4	4	4
FAC4	ratio	1.0	0.943	0.943	4	2	3
FAC5	ratio	0	0	0	4	4	4
FAC6	ratio	1.0	0.943	0.943	4	2	2
FAC7	ratio	1.0	0	0	4	4	4
FERT(I)	Kg/ha.yr	40	10	10	4	4	4
FLOW(I)	l/yr	0.78×10^9	0	0	4	4	4
SLFPH	ppm	500	500	500	4	4	4
FACRE	cm^2	0.12×10^{14}	0.322×10^{14}	0.622×10^{14}	4	1	1
CAP	number	0.5×10^6	0.36×10^7	0.125×10^8	4	1, 5	3
DMCONC	MGD/cap.	0.1×10^{-4}	0.71×10^{-5}	0.71×10^{-5}	1	1	1
DPMIN	g/m^3	2.0	0	0	4	4	4
SACRE	cm^2	0.5×10^{10}	0.36×10^{10}	0.125×10^{11}	4	6	6
UACRE	cm^2	0.25×10^{13}	0.17×10^{14}	0.304×10^{14}	4	6	6
XNACRE	cm^2	0.6×10^{14}	0.66×10^{15}	0.4×10^{15}	4	1	1
XDACRE	cm^2	0.5×10^{12}	0.64×10^{14}	0.32×10^{14}	4	6	6
RWACRE	cm^2	0.127×10^{13}	0.578×10^{15}	0.257×10^{15}	4	1	1
WACRE	cm^2	0.177×10^{13}	0.578×10^{15}	0.257×10^{15}	4	1	1
XFACRE	cm^2	0.904×10^{12}	0	0	4	1	1
GACRE	cm^2	0.13×10^{13}	0.128×10^{15}	0.639×10^{14}	4	1	1
RFLO	l/yr	0	0	0.167×10^{15}	4	4	3
RCONC	g/l	0	0	0.198×10^{-4}	4	4	3
R	NA[a]	50	100	100	7	7	7
P	NA	1.0	0.5	0.5	7	7	7
FA1	ratio	0.6	0.8	0.8	4	4	4
FA2	ratio	0.35	0.2	0.2	4	4	4
FA3	ratio	0.05	0	0	4	4	4

References

1. Water Resources Council (1968); 2. Lee (1972); 3. Federal Water Pollution Control Agency (1968);
4. Estimated based on judgement of project staff; 5. U.S. Department of Commerce (1972);
6. Based on population estimate; 7. Based on Wischmeier (1968).

SECTION VII
MANAGEMENT TACTICS FOR CONTROLLING PHOSPHORUS

DEFINITION OF CONTROL TACTICS

Management tactics refer to the range of methods and techniques which could be applied in controlling phosphorus inputs to surface waters. Strategies are combinations or sets of tactics used in a coordinated manner for basin-wide management. The purpose of this section of the report is to identify and describe potential control tactics for controlling phosphate flows from the major sources described in Sections V and VI. In Section VIII these tactics are integrated into overall strategies for testing and application in case studies of hypothetical and actual river basin systems.

To structure the phosphate flow model and to facilitate the development and analysis of management strategies, the sources of phosphorus to surface waters are grouped according to the following major activity systems:

1. Nonbasin
2. Agriculture
3. Urban and rural watersheds

4. Domestic
5. Industrial
6. Mining
7. Animal production

Likewise, the tactics or methods of control are grouped according to the following classifications:

1. Supply and demand as applied to consumer habits and production activities
2. Resource control: Mining and manufacturing
3. Management of phosphate use
4. Management of phosphate discharges
5. Judicial controls
6. Wastewater treatment
7. Lake renovation

As an overview, the matrix in Figure 28 illustrates the general relationship between phosphorus sources and the control tactics available. An "X" in the matrix indicates that the group of controls is generally applicable to the activity source. The problem of developing management strategies, viewed in the context of the matrix, amounts to formulating a coordinated set of specific controls from the available tactics to be used in reducing phosphate discharges from the activity systems. Procedures for examining the combination of controls in order to identify the overall best strategy are treated in Section VIII.

Looking more specifically at the phosphate sources within each activity system, the flow diagram of Figure 29 illustrates for which sources the

(X) Group of control methods generally applicable to activity source

Strategic Concept of Controls and Phosphorus Generating Activities	A Supply and Demand	B Resource Controls (mining and manufacturing)	C Management of P Uses	D Management of P Discharges	E Judicial Controls	F Wastewater Treatment	G Lake Renovation
1. Natural Processes						X	X
2. Agriculture	X		X	X	X	X	X
3. Urban/Rural Watersheds	X		X	X	X	X	X
4. Domestic	X		X	X	X	X	X
5. Industrial	X	X	X	X	X	X	X
6. Mining	X	X		X	X	X	X
7. Animal Production	X		X	X	X	X	X

Figure 28. Applicable control methods for phosphorus generating activities.

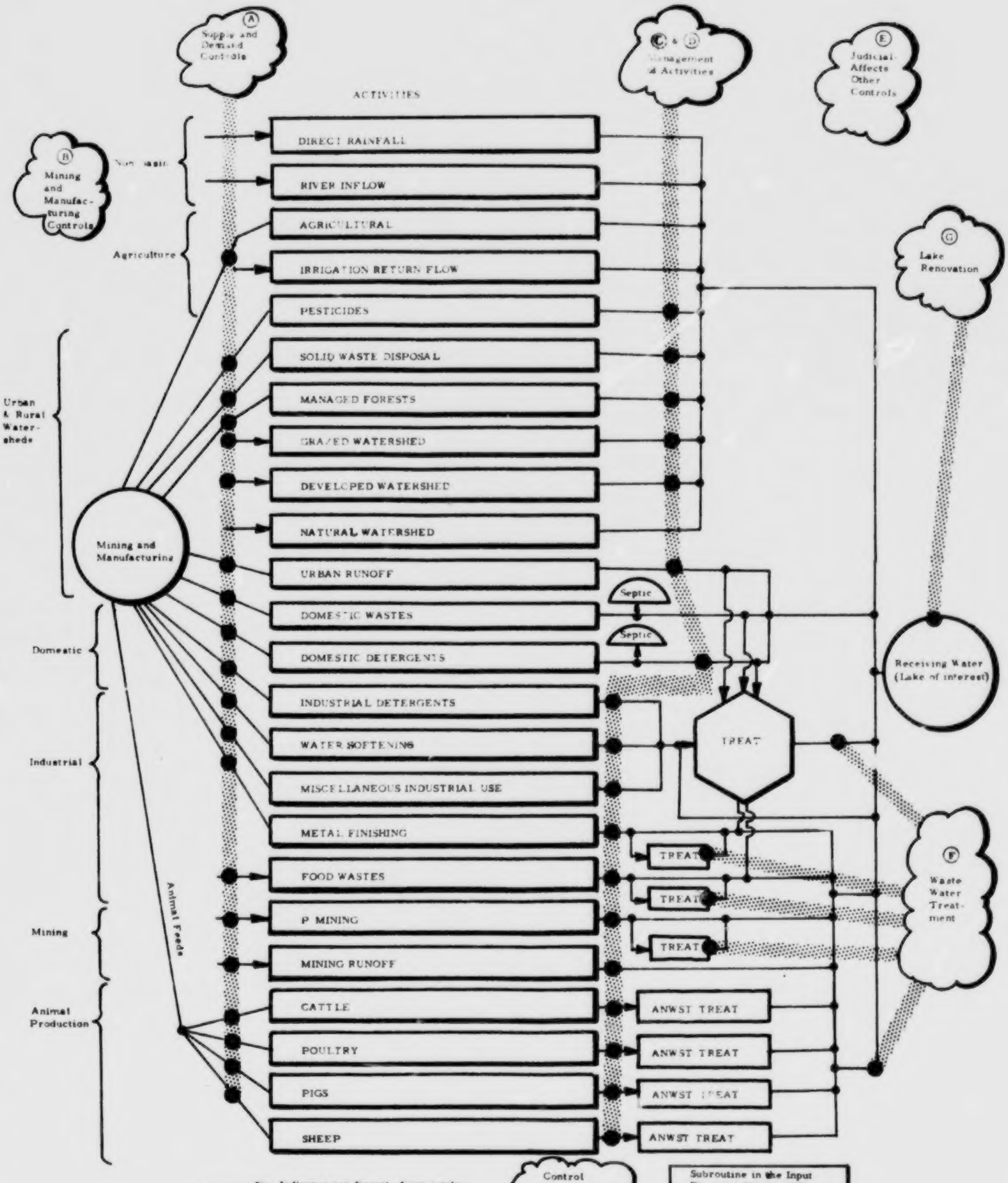

Ⓐ Supply and Demand Controls
Ⓑ Mining and Manufacturing Controls
Ⓒ & Ⓓ Management of Activities
Ⓔ Judicial Affects Other Controls
Ⓖ Lake Renovation
Ⓕ Waste Water Treatment
ACTIVITIES
Non basin
Agriculture
Urban & Rural Watersheds
Domestic
Industrial
Mining
Animal Production
Mining and Manufacturing
Animal Feeds
DIRECT RAINFALL
RIVER INFLOW
AGRICULTURAL
IRRIGATION RETURN FLOW
PESTICIDES
SOLID WASTE DISPOSAL
MANAGED FORESTS
GRAZED WATERSHED
DEVELOPED WATERSHED
NATURAL WATERSHED
URBAN RUNOFF
DOMESTIC WASTES
DOMESTIC DETERGENTS
INDUSTRIAL DETERGENTS
WATER SOFTENING
MISCELLANEOUS INDUSTRIAL USE
METAL FINISHING
FOOD WASTES
P MINING
MINING RUNOFF
CATTLE
POULTRY
PIGS
SHEEP
Septic
Septic
TREAT
TREAT
TREAT
TREAT
ANWST TREAT
ANWST TREAT
ANWST TREAT
ANWST TREAT
Receiving Water (Lake of interest)
Indicates not directly from mining
Control Tactics
Subroutine in the Input Program (Section VI)

Figure 29. Control points superimposed on the phosphorus activity analysis showing the major application points for pertinent control tactics (see Table 37).

]

general categories of control methods are applicable. Figure 28 emphasizes that the point at which controls are applied is also an important element of strategy. Table 37 provides a detailed breakdown of the options available within each class of control tactics. These approaches include both technological and management (economic, legal, social, and educational) possibilities.

Using Table 37 as an outline, the function, operation, and implementation of various methods and techniques for control are discussed in this section. The flow diagram for each phosphate mobilizing activity (Figures 30 to 34) illustrates where the full range of possible control tactics could be applied in the system. To the left of the dotted line, the boxes in each flow diagram illustrate the human wants giving rise to the demand for and supply of phosphorus products; to the right of the line are the physical processes by which the phosphorus then finds its way into receiving waters. On the arrows connecting the boxes in Figures 30 to 34 are listed the possible controls (keyed to the listing in the outline of Table 37) which might be applied to reduce phosphate flows at that point. Examinations of the diagrams reveal the large number of possible combinations of methods and points of intervention in the system. Clearly all of these combinations cannot be discussed in detail. However, from the combinations shown in the figures, strategies are developed in Section VIII that seem to be most promising and effective. These strategies are then tested in the phosphorus flow model (Figure 29) and analyzed as to their effectiveness for the case study areas.

Table 37. SUMMARY LISTING OF CONTROL TACTICS

A. Supply and demand (applies to consumer habits and producer activities)

  1. Excise taxes or other taxes
  2. Subsidies (nonphosphorus products)
  3. Tax breaks and credits
  4. Price controls
  5. Advertising and education
  6. Nonmonetary recognition
  7. Content labeling
  8. Moral suasion
  9. Boycotts

B. Resource control, mining and manufacturing

  1. Requirements for recycling
  2. Phosphate mining restrictions (rationing)
  3. Manufacturing/production restrictions
  4. Emission controls

C. Management of phosphorus uses

  1. Resource and product substitution
  2. Technology improvements in processes or uses
  3. Monitor requirements with enforcement of application rates (e.g., fertilizer)
  4. Recycling and reclamation

D. Management of phosphorus discharges

  1. Imposition of pollution standards
  2. Land management practices

    a. Reduction of cultivated acreage
    b. Increased or decreased fertilizer use
    c. Erosion control--cropping and fertilizer management
    d. Erosion control--irrigation practices
    e. Erosion control--green belts and buffer zones
    f. Solid waste recycling

Table 37. CONTINUED

- 3. Land use controls
    - a. Zoning
    - b. Licensing
    - c. Leasing
    - d. Codes and subdivision regulations
    - e. Permits
- 4. Solid waste management
    - a. Disposal regulation
    - b. Fees
- 5. Effluent charges
- 6. Bans
- 7. Fines

E. Judicial controls

- 1. Judicial review
- 2. Class action
- 3. Common law remedies (nuisance, trespass, negligence)

F. Wastewater treatment--for phosphorus removal

G. Lake modification

CONCEPTS OF CONTROL TACTICS

Major concepts of the various control tactics listed in Table 37 have been subjected to analysis according to several common criteria. These include a brief description of the control tactic including where it is applied, to which points in the system, and to which activities such as feedlots, etc. Then the effects of the control tactic in changing phosphorus output for particularly important activities are described. Also the elements which make it a controllable variable may be discussed;

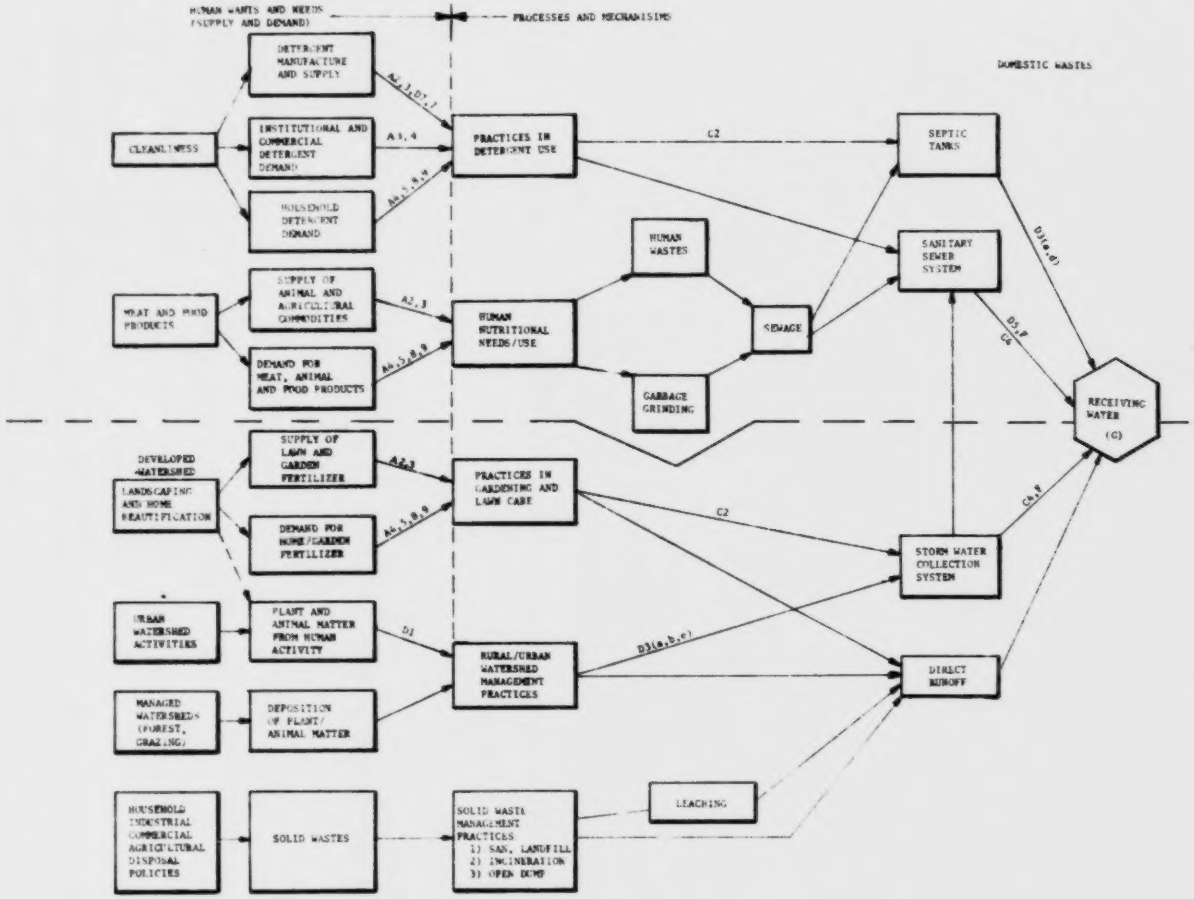

HUMAN WANTS AND NEEDS (SUPPLY AND DEMAND)
PROCESSES AND MECHANISIMS
DOMESTIC WASTES
CLEANLINESS
DETERGENT MANUFACTURE AND SUPPLY
INSTITUTIONAL AND COMMERCIAL DETERGENT DEMAND
HOUSEHOLD DETERGENT DEMAND
A2,3,D7,7
A3,4
A4,5,8,9
PRACTICES IN DETERGENT USE
C2
SEPTIC TANKS
MEAT AND FOOD PRODUCTS
SUPPLY OF ANIMAL AND AGRICULTURAL COMMODITIES
DEMAND FOR MEAT, ANIMAL AND FOOD PRODUCTS
A2,3
A4,5,8,9
HUMAN NUTRITIONAL NEEDS/USE
HUMAN WASTES
GARBAGE GRINDING
SEWAGE
SANITARY SEWER SYSTEM
D3(a,d)
D5,F
C6
RECEIVING WATER (G)
DEVELOPED WATERSHED
LANDSCAPING AND HOME BEAUTIFICATION
SUPPLY OF LAWN AND GARDEN FERTILIZER
DEMAND FOR HOME/GARDEN FERTILIZER
A2,3
A4,5,8,9
PRACTICES IN GARDENING AND LAWN CARE
C2
STORM WATER COLLECTION SYSTEM
C6,F
URBAN WATERSHED ACTIVITIES
PLANT AND ANIMAL MATTER FROM HUMAN ACTIVITY
D1
MANAGED WATERSHEDS (FOREST, GRAZING)
DEPOSITION OF PLANT/ ANIMAL MATTER
RURAL/URBAN WATERSHED MANAGEMENT PRACTICES
D3(a,b,e)
DIRECT RUNOFF
HOUSEHOLD INDUSTRIAL COMMERCIAL AGRICULTURAL DISPOSAL POLICIES
SOLID WASTES
SOLID WASTE MANAGEMENT PRACTICES
1) SAN. LANDFILL
2) INCINERATION
3) OPEN DUMP
LEACHING

Figure 30. Control tactics applied to urban and rural watersheds and domestic wastes.

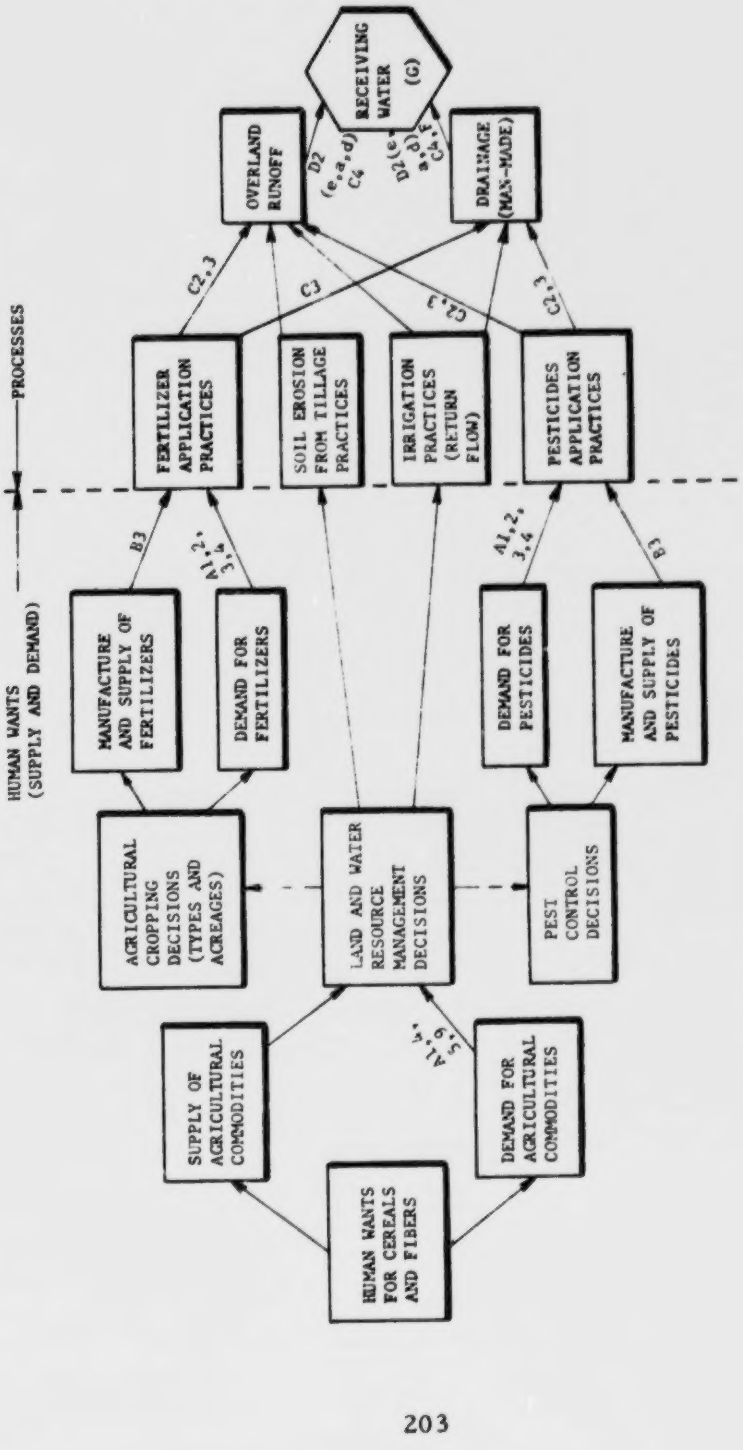

HUMAN WANTS (SUPPLY AND DEMAND)
PROCESSES
HUMAN WANTS FOR CEREALS AND FIBERS
SUPPLY OF AGRICULTURAL COMMODITIES
DEMAND FOR AGRICULTURAL COMMODITIES
A1,4, 5,6
AGRICULTURAL CROPPING DECISIONS (TYPES AND ACREAGES)
LAND AND WATER RESOURCE MANAGEMENT DECISIONS
PEST CONTROL DECISIONS
MANUFACTURE AND SUPPLY OF FERTILIZERS
DEMAND FOR FERTILIZERS
DEMAND FOR PESTICIDES
MANUFACTURE AND SUPPLY OF PESTICIDES
B3
A1,2, 3,4
A1,2, 3,4
B3
FERTILIZER APPLICATION PRACTICES
SOIL EROSION FROM TILLAGE PRACTICES
IRRIGATION PRACTICES (RETURN FLOW)
PESTICIDES APPLICATION PRACTICES
C2,3
C3
C2,3
C2,3
OVERLAND RUNOFF
DRAINAGE (MAN-MADE)
D2 (e,a,d) C4
D2(e, a,d) C4,F
RECEIVING WATER (G)

Figure 31. Control tactics applied to agriculture.

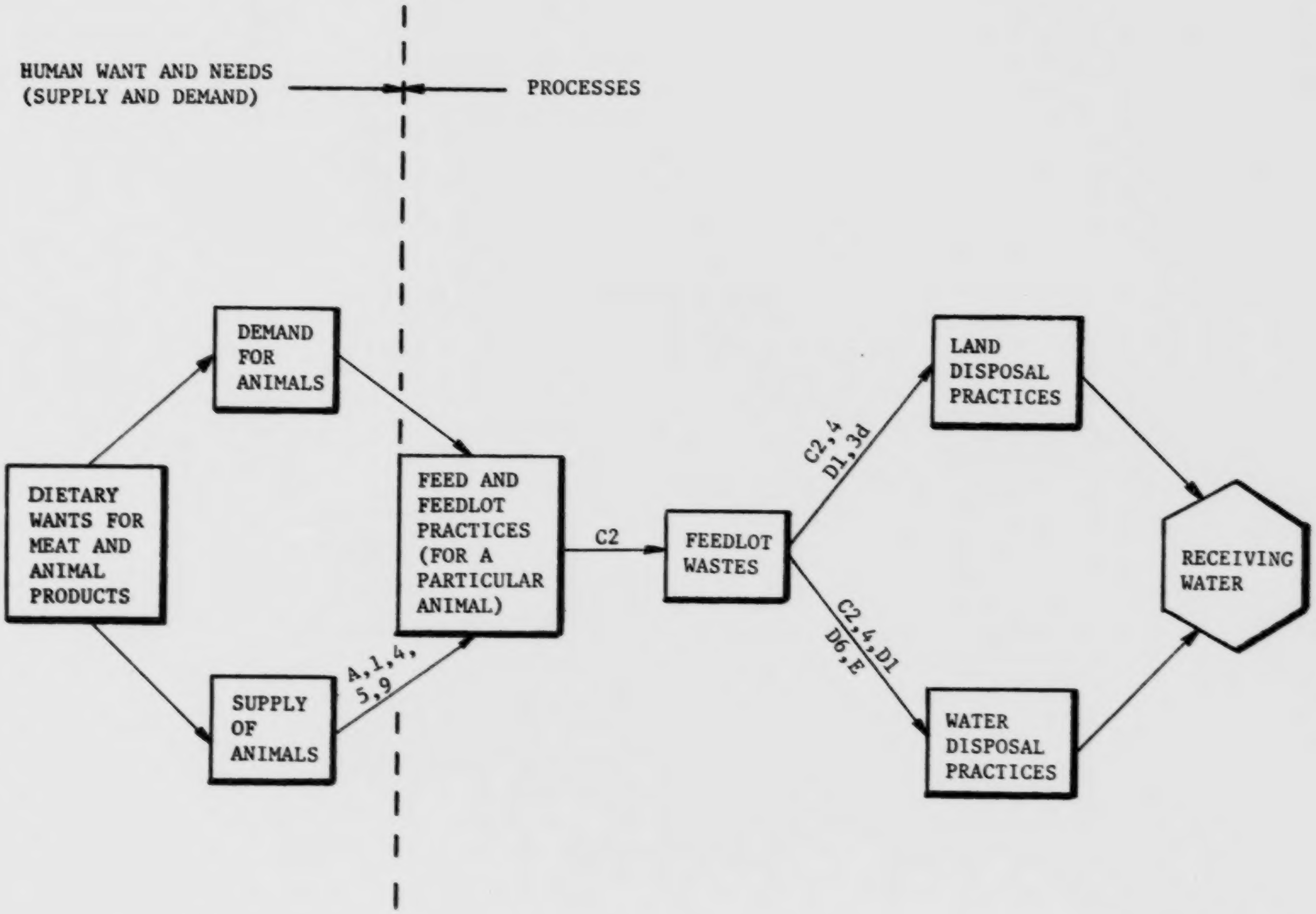

HUMAN WANT AND NEEDS (SUPPLY AND DEMAND)
PROCESSES
DIETARY WANTS FOR MEAT AND ANIMAL PRODUCTS
DEMAND FOR ANIMALS
SUPPLY OF ANIMALS
A,1,4, 5,9
FEED AND FEEDLOT PRACTICES (FOR A PARTICULAR ANIMAL)
C2
FEEDLOT WASTES
C2,4 D1,3d
C2,4,D1 D6,E
LAND DISPOSAL PRACTICES
WATER DISPOSAL PRACTICES
RECEIVING WATER

Figure 32. Control tactics applied to animal waste production.

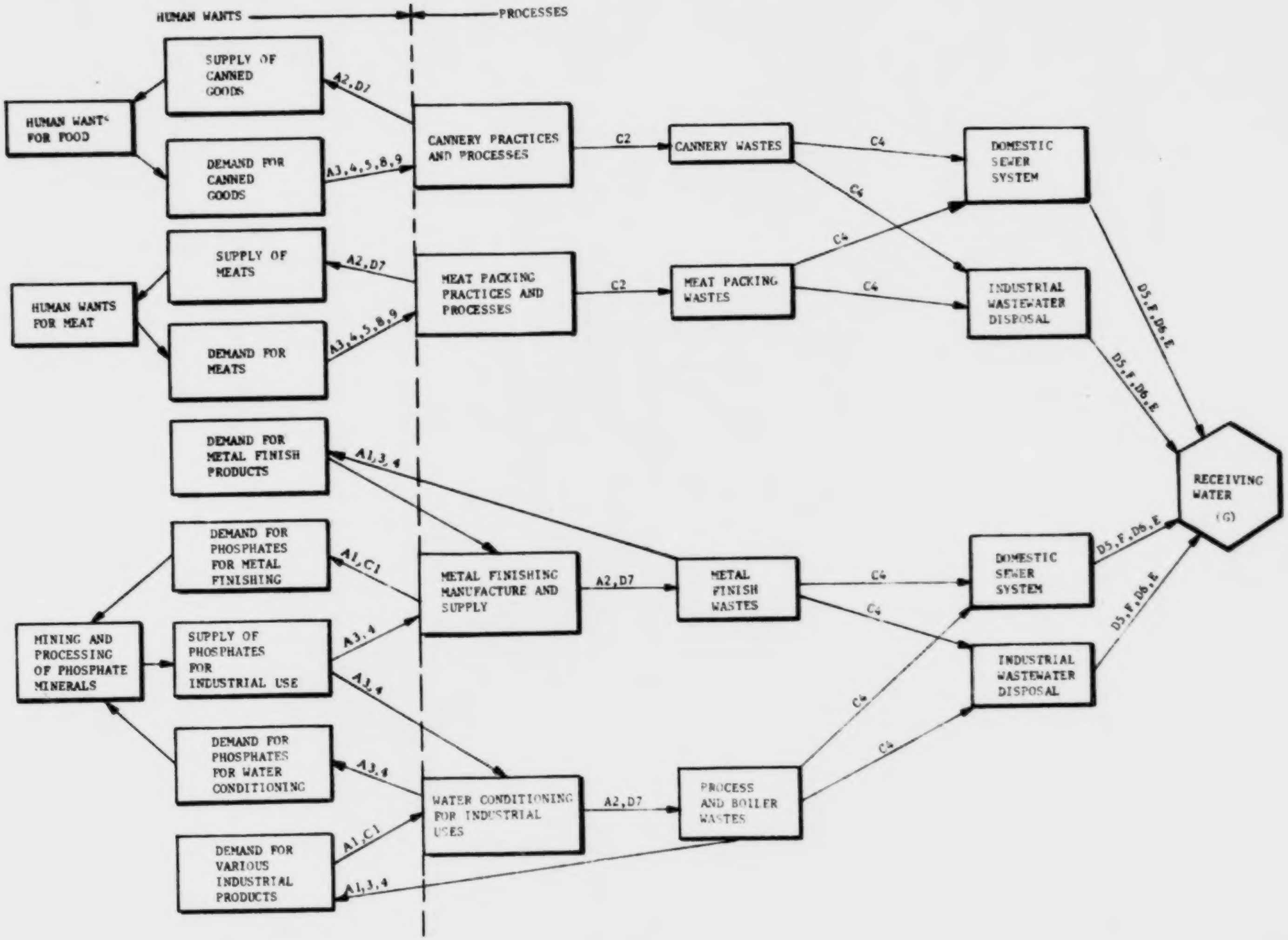

HUMAN WANTS
PROCESSES
HUMAN WANTS FOR FOOD
SUPPLY OF CANNED GOODS
DEMAND FOR CANNED GOODS
A2,D7
A3,4,5,8,9
CANNERY PRACTICES AND PROCESSES
C2
CANNERY WASTES
C4
C4
DOMESTIC SEWER SYSTEM
HUMAN WANTS FOR MEAT
SUPPLY OF MEATS
DEMAND FOR MEATS
A2,D7
A3,4,5,8,9
MEAT PACKING PRACTICES AND PROCESSES
C2
MEAT PACKING WASTES
C4
C4
INDUSTRIAL WASTEWATER DISPOSAL
D5,F,D6,E
D5,F,D6,E
DEMAND FOR METAL FINISH PRODUCTS
A1,3,4
DEMAND FOR PHOSPHATES FOR METAL FINISHING
A1,C1
METAL FINISHING MANUFACTURE AND SUPPLY
A2,D7
METAL FINISH WASTES
C4
C4
DOMESTIC SEWER SYSTEM
RECEIVING WATER (G)
D5,F,D6,E
MINING AND PROCESSING OF PHOSPHATE MINERALS
SUPPLY OF PHOSPHATES FOR INDUSTRIAL USE
A3,4
A3,4
INDUSTRIAL WASTEWATER DISPOSAL
D5,F,D6,E
DEMAND FOR PHOSPHATES FOR WATER CONDITIONING
A3,4
WATER CONDITIONING FOR INDUSTRIAL USES
A2,D7
PROCESS AND BOILER WASTES
C4
C4
DEMAND FOR VARIOUS INDUSTRIAL PRODUCTS
A1,C1
A1,3,4

Figure 33. Control tactics applied to the industrial sector.

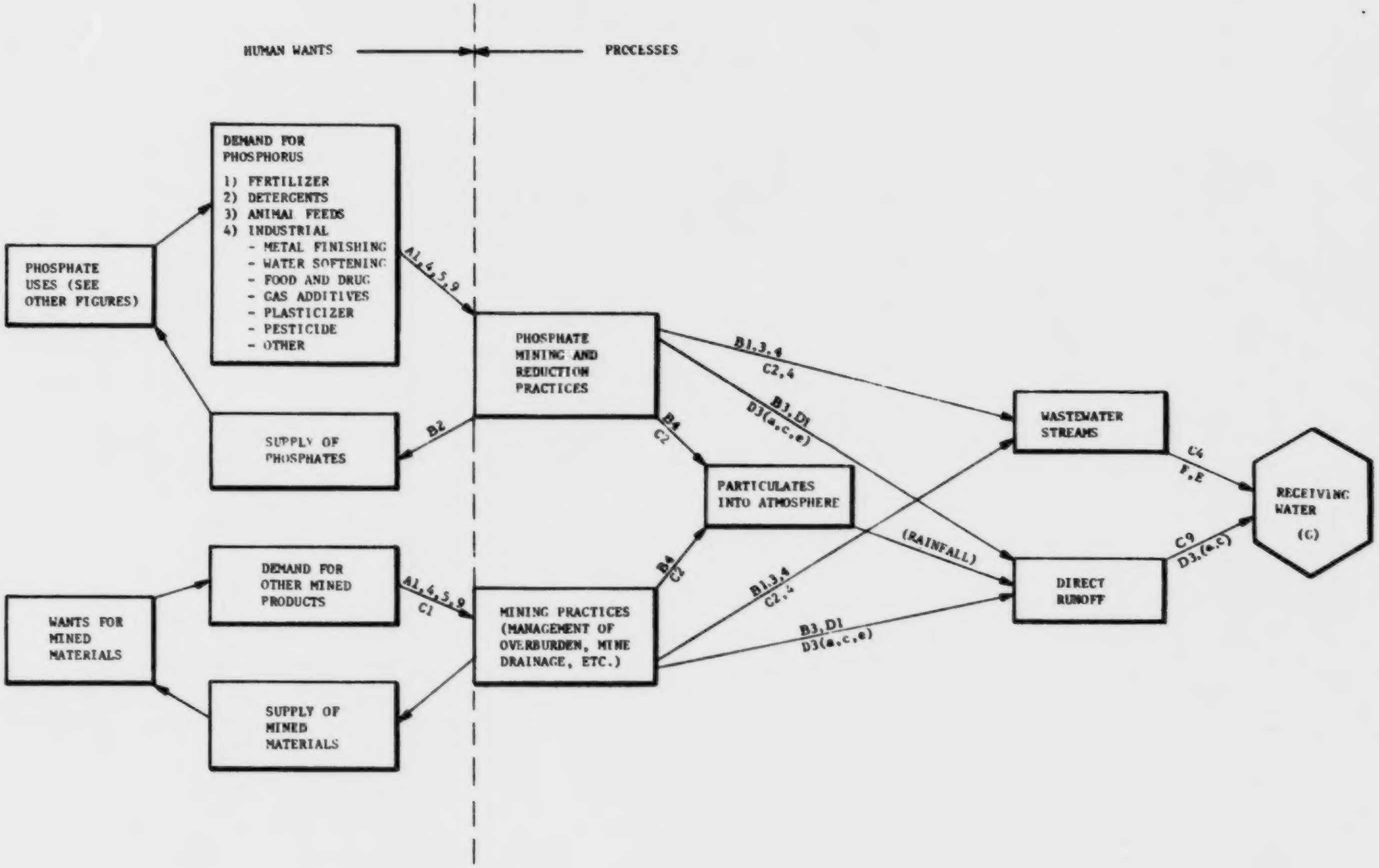

HUMAN WANTS
PROCESSES
PHOSPHATE USES (SEE OTHER FIGURES)
DEMAND FOR PHOSPHORUS
1) FERTILIZER
2) DETERGENTS
3) ANIMAL FEEDS
4) INDUSTRIAL
- METAL FINISHING
- WATER SOFTENING
- FOOD AND DRUG
- GAS ADDITIVES
- PLASTICIZER
- PESTICIDE
- OTHER
SUPPLY OF PHOSPHATES
A1,4,5,9
B2
PHOSPHATE MINING AND REDUCTION PRACTICES
WANTS FOR MINED MATERIALS
DEMAND FOR OTHER MINED PRODUCTS
SUPPLY OF MINED MATERIALS
A1,4,5,9
C1
MINING PRACTICES (MANAGEMENT OF OVERBURDEN, MINE DRAINAGE, ETC.)
B4
C2
B4
C2
PARTICULATES INTO ATMOSPHERE
B1,3,4
C2,4
B3,D1
D3(a,c,e)
B1,3,4
C2,4
B3,D1
D3(a,c,e)
(RAINFALL)
WASTEWATER STREAMS
DIRECT RUNOFF
C4
F,E
C9
D3,(a,c)
RECEIVING WATER
(C)

Figure 34. Control tactics applied to mining wastes.

how tactics are combined to make a strategy set, how the tactic works and is implemented, and the cost of each tactic or combination of tactics (strategy) may be described where data justify the discussion. These concept discussions allow development of feasible strategies for phosphorus control. The following discussion sections are keyed to the listings in Table 37.

A. Supply and Demand Controls

Supply and demand controls refer to the methods and techniques that can be used to alter phosphate producing activities or to change or modify consumer habits and behavior relative to phosphate-bearing products. The controls fall into two broad categories: (1) Those which are effected through the economic market itself (excise taxes, subsidies, and price controls); or (2) those which attempt to alter the attitudes of consumers or producers in the economic market (e.g., advertising, labeling, boycotts).

1. Excise Taxes--

General applications--Excise taxes are a series of levies imposed on specific commodities or groups of commodities. They may be quoted as a percentage of retail price, *ad valorem*; or as a specific amount per commodity sold, unit tax.

While several reasons justify their existence, three dominate: (1) To correct existing external diseconomies in the system by extracting the true social cost of production from the buyer of the taxed commodity;

(2) to generate revenue (usually used to finance programs related to the commodity); and (3) to alter consumption patterns deemed undesirable by representatives of society. The first group is relatively new and consists of emission taxes on air pollutants, and charges on various uses of public lands. The second group, often referred to as a tie-in-tax, is represented by gasoline taxes used to finance highway construction, and "addictive" excises on liquor and tobacco. The final group consists of sumptuary or luxury excises. Excises applied to phosphate pollution control would of necessity contain elements of all three. They would help adjust for diseconomies, help finance treatment facilities, and change consumption patterns toward nonphosphate products.

An excise tax could be applied at several points in the system:

1. On sales from the mine
2. On sales of pesticides
3. On sales of fertilizer
4. On detergent sales
5. On water softening equipment
6. On sales of meat if one type of animal produces more phosphate than some others

An excise tax on these sales would make this input more expensive to the industries or consumers using it. If effective, this would induce them to seek cheaper alternatives (substituting effect) or to find ways to cut down on the use of phosphorus (income effect). It would, if the tax could not be passed along, reduce the profitability of production and hence lead to a cutback in supply.

An excise tax is most effective and most desirable when dealing with a good (bad) commodity which has effective alternatives and which is nonnecessary (relatively elastic) in nature.

A tax on sales from the mine would be relatively cheap to administer since it is mined only a few places. It would be a hidden tax to the consumer which might be desirable from a political standpoint. It would be a nonselective levy and would restrict all uses of phosphorus regardless of their desirability. The tax burden would fall most heavily on those who had no good input alternatives. As mentioned, it would not be a tax observable to the consumer and would not, therefore, act as a signaling service to them that the government was wishing to cut down on phosphorus use. It is a tax unlikely to be applied at the local or state level because of the direct effect it would have on the mining operation, unless there was some local feeling that the resource needed to be conserved.

In the case of pesticides, fertilizer, and water softening where only inferior alternatives are available, its only effect would be to cut back on usage. Whether or not it was effective would depend on whether or not the increase in cost (owing to the tax) was sufficient to outweigh the additional revenue from increased production.

Finally, in the case of detergent or meat sales, where there does exist real alternatives, the effect could be substantial provided the tax was large enough to alter costs not only relatively, but absolutely. If the alternative is inferior (soap does not clean as well as detergent), however, then the impact will not be as great. If the inferiority is psychological rather than physical, then a tax would need to be combined with some kind of advertising campaign to break down the psychological barriers.

An excise tax generates revenue and one of the problems with such a system has always been that governments form a strong attachment to the revenue, especially when it goes into the general fund. As a result, rates are frequently kept low enough so as not to hinder production and consumption in any appreciable fashion.

Application of excise tax to detergents--Taxes are an important management tool and so this particular situation will be discussed extensively. To illustrate what would happen if an excise tax were applied to detergents, two approaches might be useful. The first is to look at a real example which closely approximates our own circumstance, the other to apply a hypothetical levy and make some best estimates as to what might occur. Margarine, a product which has been extensively taxed, has a close substitute, butter, just as phosphate detergents have substitutes of low phosphate detergent and/or soap.

Margarine was developed in response to a competition sponsored by Napoleon the Third to ease a butter shortage in France. It was an instant success with the public, but also formed some obvious enemies. It was attacked by some as an artificial substance and therefore undesirable and unhealthy. Attempts were made in this country in the late 1800's to ban its use outright but such laws were judged unconstitutional by the courts. Laws were then passed specifying its color (white) and conditions under which it could be sold. One wonders what might happen if a law were passed requiring all detergent that is sold to be colored black. In addition, an excise tax was levied on margarine at the federal level and by most states as well. There is no question that when the tax was high enough to make butter the cheaper product that margarine sales fell to extremely low levels. Generally butter was still more expensive and margarine became therefore, in spite of the tax, increasingly popular. After the law regarding color was eliminated, the shift to margarine was particularly pronounced.

What the tax really did was to generate funds for governmental use, perhaps to subsidize dairies for their lost sales. It became clear that the government became very attached to the revenues being generated and began gradually looking at the levy as a tax instrument rather than as a regulatory device. If there is no justifiable reason to regulate margarine, then the unfairness of taxing it and not butter becomes apparent. Today there are only a couple of states left which levy a tax on margarine. (A case history for the State of Utah can be found in Appendix E.)

The experience with the tax on margarine clearly illustrates that if the tax is high enough to alter comparative prices relative to a substitute it will be effective. If it does not alter them it can be a considerable source of funds. Finally, the collecting of funds in this way will only be politically justifiable provided that consumption of the product is causing real damage to individuals or their environment.

The second way of looking at the excise tax is to imagine what would happen if a tax were placed on all detergents. Production figures were used in this analysis because they were most available. A look at the export figures indicated that less than two percent of detergent produced in the United States is sold abroad so that production serves as a good proxy for consumption. This result is shown in Table 38. The next two tables (Tables 39 and 40) show the loss of sales and the revenue which could be collected if the various rates of tax were applied. The E in each case refers to elasticity or the assumption that is being made about lost sales. An E of 1 means that a one percent increase in price (because of the tax) leads to a one percent decrease in sales. In all cases it is assumed the tax is borne by the consumer. Except in the extreme case of $E = 0$ (no loss of sales), there is some finite tax rate which will maximize revenues. This rate becomes smaller as E rises.

For comparative purposes, in Tables 39 and 40 liquid detergents have been converted to dry by taking value equivalents. The numbers in Table 40 are estimates. It is obvious from these tables that a national excise tax on detergents would raise large sums of money which could go a long way towards covering the costs of treatment.

2. Subsidies--

According to a Congressional Report by the Joint Economic Committee in 1960:

> A subsidy is an act by a governmental unit involving either 1) a payment; 2) a remission of charges; or 3) supplying commodities at less than cost or market price, with intent of achieving a particular economic objective, most usually the supplying to a general market a product or service which would be supplied in as great a quantity only at a higher price in the absence of the payment or remission of charges.

Table 38. ESTIMATED DRY WEIGHT OF ALL DETERGENTS CONSUMED PER PERSON IN THE UNITED STATES[a]

	Dry kgs, millions	Population, thousands	Per Capita, kgs
1954	1,500	161,191	9.3
1958	1,854	173,320	10.7
1963	2,000	188,483	9.9
1967	2,408	197,457	12.2
1973	2,752 est.	209,000 est.	13.2 est.

[a] 1954, 1957, 1963, and 1967 data from survey of manufacturers. 1973 data estimated using previous figures (U.S. Department of Commerce, 1968).

There are various reasons currently used to justify such payments. Shoup (1969) lists the following: (1) Internalize externalities; (2) redistribution of income; (3) consumer protection; and (4) facilitation of the dynamic process.

Often an item is said to have benefits which are external to the consumer, which accrue to society as a whole and which are not considered by the individual in making his consumption decisions. Since price does not represent the true value to society, it is argued that this leads to underconsumption of the goods. Examples often cited are education and various disease prevention vaccines. In order to stimulate consumption of these items to the desired level and the correct level for society as

Table 39. REVENUE FROM DETERGENT EXCISE TAX AT DIFFERENT RATES AND ELASTICITIES (1967 DATA)

(quantities are in million kg and tax revenues in dollars)[a]

Tax rate/unit	0	0.05	0.10	0.15	0.20	0.25
Case 1	E = 1.05					
Quantity	3530	2706	2047	1508	1059	683
Tax revenue	0	289.01	450.89	498.21	466.55	376.46
Case 2	E = 1.0					
Quantity	3530	2745	2117	1604	1177	819
Tax revenue	0	302.33	466.44	530.11	518.37	451.09
Case 3	E = 0.95					
Quantity	3530	2784	2188	1701	1294	954
Tax revenue	0	306.65	481.99	561.91	570.19	525.70
Case 4	E = 0.90					
Quantity	3530	2823	2259	1797	1412	1090
Tax revenue	0	310.97	497.54	593.71	622.01	600.33
Case 5	E = 0.75					
Quantity	3530	2941	2470	2086	1765	1496
Tax revenue	0	323.92	544.18	689.11	777.48	824.18
Case 6	E = 0					
Quantity	3530	3530	3530	3530	3530	3530
Tax revenue	0	338.7	777.4	1166.0	1554.8	1943.5

[a] Converted liquid into dry equivalent values by assuming that the average price of all units (lbs and gal) was \$0.20. Thus, total units = 1554.8/0.20 = 7774 million lbs or 3530×10^6 kg. \$1554.8 millions was the total value of detergents produced in 1967.

Table 40. REVENUE FROM DETERGENT EXCISE TAX AT DIFFERENT RATES AND ELASTICITIES (ESTIMATED 1973 DATA)

(quantities are in million kg and tax revenues in dollars)[a]

Tax rate/unit	0	0.05	0.10	0.15	0.20	0.25
Case 1	E = 1.05	0.2222	0.4	0.5454	0.6666	0.7679
Quantity	3852	2953	2234	1278	1156	746
Tax revenue	0	325.27	492.13	571.11	509.22	410.89
Case 2	E = 1					
Quantity	3852	2996	2311	1796	1284	894
Tax revenue	0	329.98	509.10	578.59	565.78	492.34
Case 3	E = 0.95					
Quantity	3852	3039	2388	1751	1412	1042
Tax revenue	0	334.69	526.07	578.59	622.24	573.78
Case 4	E = 0.9					
Quantity	3852	3082	2465	1961	1541	1190
Tax revenue	0	339.41	543.04	648.01	678.90	655.23
Case 5	E = 0.75					
Quantity	3852	3210	2696	2276	1926	1634
Tax revenue	0	353.55	593.95	752.13	848.58	899.56
Case 6	E = 0					
Quantity	3852	3852	3852	3852	3852	3852
Tax revenue	0	424.25	848.5	1272.75	1697.0	2121.25

---

[a] Converted liquid into dry equivalent values by assuming dry to liquid ratio continues as in 1967. Thus, total units = 1.4 x 6061 = 8485 million lbs. Data taken from Table 38.

a whole, the government subsidizes the product through one of the three methods in the previous quote.

Frequently, the humanitarian nature of our society considers the redistribution of income justification enough for a subsidy. For this reason such subsidies as food stamps, unemployment compensation, and services to the disabled, the aged, and war veterans have come into existence.

Protection of various industries developed for a variety of reasons. Often a specialized input (usually labor) becomes highly immobile and as the market in which this industry functions weakens, subsidies become necessary in order to continue the employment of this factor. Our agriculture price supports stem from such beliefs. Similarly, if domestic demands for a foreign made item cause a serious balance-of-payments deficit, subsidized production of that item is often preferable to a tariff.

Finally, subsidies can be used to facilitate dynamic adjustment. If a large manufacturing plant is constructed in an economically depressed area, it may be that the increased amount of taxes and decreased aid payments will more than recoup the costs of subsidizing the construction in a short period of time. Therefore, the government might want to facilitate or enhance the opportunities of location of this firm in the area through subsidy measures (Laird and Rinehart, 1967).

Subsidies are negative taxes and could be used at similar points to excises and represent rewards rather than penalties for specified actions. They could be used to cheapen the cost of substitute products or to pay for lost revenues from decreased production.

Subsidies represent a drain on the public treasury and on equity grounds would be used when it is felt that the benefit is general and not specific. Laws allowing subsidies must be carefully written so as to ensure that the subsidy is not collected unless there is a noticeable change in behavior. Subsidies could also be used to locate phosphorus using activities in the most appropriate places by rewarding businesses and activities for locating in desired areas.

Subsidies could be used to encourage appropriate technological innovations by rewarding the desired behavior. The Department of Agriculture has had several such programs, the most conservation-minded of which was the Rural Environmental Assistance Program which has now been discontinued. It provided cost sharing to farmers for environmentally desirable changes. The Farmers Home Administration also provides loans and grants for conservation programs. Loans are at favorable rates of interest for extended periods of time (3.5-5 percent and 30-40 years).

3. Tax Breaks and Credits--

Closely aligned to subsidies are tax breaks or credits. These are given through tax laws either by a reduction in the size of the tax base or through preferential rates on that base. The income tax laws are full of such breaks (sometimes called loopholes). The purpose of such breaks is to encourage certain desired types of behavior.

Tax breaks can be given to anyone or anything that pays taxes. The most notorious example of tax breaks is the mineral depletion allowance. This allows a mining firm to deduct a percentage of its gross income--up to 50 percent of its taxable income each year--in addition to the other "ordinary" deductions. It is not a substitute for the regular depreciation that all firms are allowed on new investment, but is an additional benefit. The depletion allowance is available each year regardless of what investment has taken place and this means that new investment could be easily written off at far more than 100 percent of value over a few years. The depletion allowance is, of course, designed to encourage production of more minerals. Several reports have indicated that they have not been very effective. Senator Gore, in discussions concerning the 1969 Tax Reform, stated that the additional reserves developed in the oil industry, above what would have taken place anyway, amounted to 150 million dollars (Department of Treasury, 1969). This was obtained at a loss to the treasury (taxpayers) of between 1 1/2 and 2 billion dollars. The 1969 Tax Reform lowered rates on the depletion allowance somewhat. In the case of phosphorus the allowance was lowered from 15 to 14 percent.

The miners of phosphorus, therefore, receive a considerable tax break. The value of mined phosphorus in 1967, the last year for which published data are available, amounted to 296.6 million dollars. At the then current rate of 15 percent, this meant an allowance of 45 million dollars could be claimed, assuming that the tax rate was 50 percent, it would have given the phosphate mining industry a tax break of 22.5 million dollars. This would be approximately the equivalent of a 4 dollar subsidy per ton of phosphate mined.

The removal of the depletion allowance would make the mining of phosphate less profitable and raise the cost to users, and would lead to a reduction in the availability and use of phosphate. The mining industry also receives other tax considerations as well but none are as large and important as this.

It is one of the problems of large organizations like the federal government that conflicts in desired goals often arise. Parts of the federal system may want to cut back on phosphate use for environmental purposes, while at the same time other parts of the system are encouraging its production.

The greatest appeal of tax breaks and credits is political. They are a subtle subsidy and may not be recognized as such. They are of generally greater value to the rich than to the poor, both firms and people. They may just be a windfall payment to a firm for doing what it would have done anyway. Among the most common loopholes available to businesses are investment credits, accelerated depreciation, and depletion allowances.

4. Price Controls--

Price controls are an attempt by government to set price and then allow production and consumption to establish their own levels. A price floor will create surpluses, a price ceiling shortages. In the first case, government must buy up the excess and stockpile it or run the risk of widespread illegal marketing. In the second, government must ration the commodity in some other way, such as waiting lists or coupons.

Under-the-table payments are always cropping up in this situation as is the case with rent controlled apartments in New York City.

Anywhere an exchange of goods for money takes place a price control could be used. In this case the relevant approach would be a price floor below which phosphorus or products made from phosphorus could not sell. Appropriate points of application might be:

1. Sales from the mine
2. Sales of pesticides
3. Sales of fertilizer
4. Sales of detergent
5. Sales of water softening equipment
6. Sales of meat

By keeping prices artificially high relative to market conditions, it would cut back on the use of phosphorus or of the phosphorus-generating product.

Price controls (ceilings) are currently in fashion. Their effect can be immediate and obvious. It shows the determination of the government to create change. However, based on past experience, price controls do not appear to be a long-run solution. The temptation to cheat and the enforcement problems connected with this policy are just too great in the long run. Punishment of wrong doers is selective, arbitrary, and generally ineffective. Price controls are best used as a last gasp or crisis measure.

5. Advertising and Education--

Advertising and education programs oriented toward controlling the use and consumption of phosphorus and phosphorus products might prove to be effective. EPA's Hooty the Owl ("Give a Hoot, Don't Pollute") might direct his attention to phosphorus pollution. His audience might be detergent-using housewives, homeowners who use phosphorus fertilizers in lawns and gardens, and farmers. Through TV and possibly the press, such a program could be expected not only to reduce levels of phosphorus consumption, but also create a broad based public awareness of the problem. The problem might be disseminated on a national basis, or directed toward locales whose eutrophication problems are acute and chronic.

The Department of the Interior's Johnny Horizon program (administered by the Bureau of Land Management) might also zero in on the problem of eutrophication. Presumably the emphasis here would be on land management practices (erosion control, proper fertilizer use, etc.), and the audience would be farmers and other land managers.

Education and advertising as a means of control should not neglect future generations of users and consumers. Films, workshops, and special projects dealing with the role of phosphorus in eutrophication and remedial measures should be incorporated in programs of environmental education in grade schools and high schools. Since erosion from agricultural lands is a principal source of phosphorus, the Future Farmers of America is one group of young people for whom an educational program might be designed.

6. Nonmonetary Recognition--

Providing nonmonetary recognition such as awards, commendations, certificates, press coverage, etc., is another possible way of motivating people to engage in sound environmental practices. This technique could probably be used most effectively in programs aimed at grade and high school students.

7. Content Labeling--

In June, 1971, the Federal Trade Commission proposed the following labeling requirement for detergents containing phosphates:

> The container of every detergent must list all ingredients by common or usual name--or if there is none, by chemical name--giving percentages by weight, and weight in grams per recommended use level of each, in descending order of predominance.

The FTC also proposed that the following statement appear on each phosphate detergent product:

> Warning: Each recommended use level of this product contains ___________ grams of phosphorus, which contributes to water pollution. Do not use in excess. In soft water areas, use of phosphate is not necessary.

A series of hearings were held both by the FTC and the House of Representatives concerning the FTC proposal during 1962. As a result of these hearings, the porposal was never implemented.

8. Moral Suasion--

Moral suasion is an appeal by the government without legal backing to an individual or group's social conscience. It is, however, frequently combined with a threat of legal action or economic sanctions which tends to improve the social conscience. President Johnson's version of moral suasion was called jawboning.

Moral suasion is most effective where the threat of sanctions is a serious and believable one, and where society's conscience is making noises. (President Kennedy's rolling back of steel prices by means of a heart to heart talk with the head of U.S. Steel (Mr. Blount) is the most widely advertized instance of this type. The government is a big consumer of steel and the price rise was unpopular, so it worked.) It also works better when the number of necessary arm twists is limited. Moral suasion could be effective with a big phosphate generator such as a mine company or a large feed yard in getting them to adopt more favorable practices.

9. Boycotts--

Consumer boycotts might provide still another means of controlling phosphorus inputs into receiving waters. The grape boycotts of 1971 and 1972 organized by Caesar Chavez and supported by the AFL-CIO for the purpose of securing union contracts for farm labor exemplifies the potential effectiveness of consumer boycotts. It might be possible for activist environmental groups to organize and gain support for a boycott of high phosphate detergents. Other possibilities are boycotts on meats traceable to polluting feedlots and nonorganically raised vegetables.

B. Resource Control--Mining and Manufacturing

Mining and manufacturing of phosphorus as a source for various industrial-domestic-agricultural uses is largely a regional activity concentrated in Florida, Tennessee, and Idaho-Wyoming mining operations (Logue, 1958). For a particular basin of interest it will frequently not be a problem. However, in the areas noted previously, eutrophication problems might arise due to discharge of waste phosphorus directly (seepage, pond dike erosion) or addition to the atmosphere and subsequent rainout.

1. Recycling Requirements--

Recycling of scarce resources has long been practiced in primitive as well as modern societies. Recycling resources which are not scarce or which would lead to a change in production economics is a rather recent concept which largely resulted from the environmental movement of the 1960's. The supply of known, available, phosphorus ores (> 8 percent phosphorus) extractable by phosphorus mining techniques is estimated to last at present use rates about 1800 years; phosphorus cannot be considered a scarce resource, especially in comparison to other elements such as helium (Institute of Ecology, 1971); thus, at present recycling would be required only from the point of view of lessening pollution.

Perhaps the most important areas applicable to recycling or multiple usage of phosphorus compounds concern its use as a nutrient for agriculture: (1) Use of effluent for irrigation waters; (2) use of biological sludges from wastewater treatment plants to reclaim soils (e.g., strip mine operations) or as a fertilizer (e.g., "Milorganite"); and (3) use of animal manures for fertilizer. The placing of farm ponds for fish aquaculture adjacent to pig farms as in Southeast Asia is an example of application of these principles to aquatic systems.

Also, it has been proposed that the calcium phosphate precipitates from phosphorus removal at the wastewater treatment plant be utilized for building blocks. This would be primarily a means of sequestering phosphates rather than recycling the phosphorus; also, it would possibly provide a dollar generating activity which would eliminate some of the cost of chemical sludge disposal, an important aspect of phosphorus removal costs.

2. Phosphate Mining Restrictions (Rationing)--

One method of enforcing recycling of phosphorus is to restrict the amount of phosphorus mining in some way, e.g., by rationing. Rationing, or the limitation in the annual amount of phosphorus mined would undoubtedly increase the cost of mined phosphorus and hence decrease the utilization of phosphorus, particularly for those phosphorus using activities which are not absolutely necessary (e.g., detergents) or which at times use more phosphorus than may be considered necessary (e.g., fertilizers). In addition, this action might increase the value of recycling phosphorus. Additional benefits from such limitation would include: (1) Preservation of resources which are strategically located; (2) maintenance of land resources in areas where land might be in short supply (e.g., Florida); (3) elimination of by-product pollution (fluoride toxicity).

However, the effects and interactions caused by limiting phosphorus mining activities would be very complex: (1) Interference with export trade of phosphorus fertilizers; (2) upset of local economy; (3) interference with food supply and possible long-term effects on U.S. agriculture; and (4) enforcement problems with illegal sales (black market). For these reasons it was decided that rationing would not be a feasible nor effective control strategy.

3. Manufacturing/Production Restrictions--

Certain aspects of the phosphorus mining and manufacturing process seem amenable to changes in process which could be controlled by various restrictions. Such changes are primarily directed at processes which produce a waste product (a presently unused resource) or at processes which are wasteful of phosphorus because of spillage and unnecessary usage. A problem associated with the mining and processing industry, particularly in the "pebble phosphorus" deposits in Florida, not so much in the hard rock deposits in Tennessee and Idaho-Wyoming, is the handling of phosphate slurries (Tyler and Waggaman, 1954). These slurries, about 33 percent of the total mined in Florida, consist of colloidal suspensions of phosphate ore which are not easily separated from water. As a result, they are disposed into large ponds for relatively indefinite storage. The ponds are eyesores and promote inefficient use of land as well as representing a possible source of phosphorus which enters the surface water via seepage or the breaking of pond dikes. Drying, direct use, and phosphorus extraction and/or benefication (increasing the phosphorus content) to allow use of this "waste product" have all been suggested as possible alternatives for handling the slurries. Direct uses as a soil amendment, addition to pasture land, and other agricultural uses are primarily limited by transportation from the regions where mixing occurs. Research is continuing on the process changes necessary to allow the utilization of slurries; at present, it does not seem feasible to force this particular process change at this time because of the economic problems.

Consideration of phosphate substitutes in cleaning and washing products are discussed elsewhere in this report. Substitutes for products used in various industrial processes such as in water conditioning products and metal finishing acids are being developed. However, these uses as present do not seem to be significant or can be handled in a better manner.

4. Emission Controls in the Mining and Manufacturing of Phosphorus--

Most controls in this industry have been directed at fluoride, a toxic contaminant in the phosphate minerals being processed (primarily a problem in the phosphorus pebble ore of Florida). Prevention of phosphorus input to surface waters is largely achieved by discharge of unusable materials to settling ponds. Seepage and dike erosion allow phosphorus to enter the surface water, but these types of inputs are not amenable to emission controls or discharge standards. States with phosphorus mining have regulations on phosphorus pollution, but because the present problem is largely accidental (dike erosion) the regulation is not generally applicable to "spill-type" additions. Monetary fines, pond dike building codes and construction safety factors, sealing of ponds to prevent seepage, could all be utilized to control this input, but other incentives, e.g., the process changes described above, might be of more long-term value as a preventative. This would be so because of the economic incentive to the producer to regain the present approximately 30 percent of the resource which is being lost. Until such process changes have been developed, emission controls seem to be a feasible alternative.

C. Management of Phosphate Uses

In those activities where phosphate is used as a part of the production process or where end products containing phosphates are used for particular purposes, there exists an opportunity for controlling the phosphate through better management of the producing or using activities. The possibilities for management of phosphate uses are described in four general areas:

1. Resource and Product Substitution--

Where there are reasonable substitutes for products or processes having phosphates, then through the use of such substitutes the phosphates wastes and residuals could be eliminated. Some of the possibilities for phosphate substitutes in production processes include the use of acids other than phosphoric in metal finishing processes, nonphosphate based processes in water conditioning, and the use of nonphosphate builders in detergents. In making such substitutes, however, care must be taken that the substitute is not a potentially greater environmental threat, such as could possibly be the case for the use of NTA in detergents. Otherwise one problem may be exchanged for another that may be more serious.

Substitutes may also be sought for other phosphate-containing products. For example, using soap to replace detergent, or the use of other types of pesticides that do not contain phosphate. In the case of either process or products, inducing substitution will virtually always require the application of other supply and demand or judicial control tactics.

2. Technology Improvements in Processes or Products--

Technology improvements in products or processes also represent a potential means of reducing phosphate residuals entering the aquatic system. These may come about through changes which reduce discharges from industrial processes such as metal finishing and water conditioning, or through improved mining practices. Some of these possibilities are elaborated in more detail in other parts of this section. However, since this area largely represents long range solutions that are not immediately implementable, there will be no further discussion.

3. Monitoring Requirements and Application Rates--

Monitoring requirements and establishing application rates and standards for use of phosphorus-containing products could do much to reduce excess concentrations of phosphorus which find their way into effluent discharges. Without precise knowledge of what is a sufficient application rate, the practicing philosophy is usually that more is better. This is often true with regard to fertilizer application for agriculture, and to lawn and garden use. Soil sampling and analysis to determine base requirements for phosphorus fertilizer applications for agriculture could do much to reduce excessive application practices which increase the concentrations of phosphorus in soil erosion and runoff into water courses. Comparison with the USDA pesticide registration program seems advisable in this regard. Likewise, guidelines for application of fertilizer in home lawn and garden use could reduce concentrations in urban storm runoff. Other areas where monitoring and guidelines could prove effective is in the separation and handling of solid wastes, such as phosphorus chemical formulations, vegetable matter, and discarded wash products, which have greater concentrations of phosphorus, and also in monitoring the handling of feedlot wastes.

4. Recycling and Reclamation--

Recycling and reclamation serve a key function in reducing phosphorus pollution by reusing phosphorus residuals in the system rather than mobilizing new phosphorus to serve the activity. Some of the possibilities of recycling, for example, include the use of wastewater effluents for irrigation water, the use of sludge from wastewater treatment operations as fertilizers and soil conditioners, and the long used practice of using animal wastes as fertilizers. Similar possibilities for recycling processes exist in mining and industrial uses (see also B. 1).

D. Management of Phosphorus Discharges

Diffuse and point sources are included in this discussion and it is management of these sources enforced by some of the controls described in Table 37 (A, E, F) which is the crux of the phosphorus control question. Managing phosphorus discharges appears to be the most logical and economical means of reducing phosphorus input to surface waters. Management implies several levels of interaction depending on whether the source is diffuse or at a point.

1. Pollution Standards--

While no specific national standards have been established for phosphorus levels in surface waters, the National Technical Advisory Committee (Water Quality Criteria, 1968) recommended the following to the states: That levels of phosphate in flowing streams should not exceed 100 μg/l, or more than 50 μ g/l where streams flow into lakes or reservoirs.

Most states have no specific criteria or standards for phosphorus levels in surface waters. An attempt cannot be made here to provide a complete summary of criteria that have been established, but the following is illustrative:

> California standard for Lake Tahoe: A mean annual concentration not greater than 7 μg/l of phosphorus at any point in the lake.
>
> Nevada standard for East Fork Carson River: Annual average of total phosphorus not to exceed 0. 1 mg/l (100 μg/l); single daily value or average not to exceed 0. 2 mg/l (200 μg/l).

> Illinois standard for Lake Michigan open water: Total phosphorus annual average not more than 0.03 mg/l (30 μg/l); single daily value or average not more than 0.04 mg/l (40 μg/l).
>
> Pennsylvania standard for all surface water: Total phosphorus not to exceed 0.10 mg/l (100 μg/l) or natural levels, whichever is greater.
>
> Indiana standard for municipal effluent: All municipalities in Great Lakes tributary basins will be required to provide at least 80 percent reduction of total phosphorus on or before the end of 1972.

A summary of water quality standards listing phosphate criteria was issued by the EPA, Office of Water Programs, on March 1, 1972.

In compliance with the 1972 amendments to the Federal Water Pollution Control Act, it is expected that many states will modify existing, or establish new, standards for phosphorus, especially with reference to the effluent from municipal treatment facilities and other point sources. Section 314 of the 1972 amendment states:

CLEAN LAKES

> SEC. 314. (a) Each State shall prepare or establish, and submit to the Administrator for his approval--
>
> (1) an identification and classification according to eutrophic conditions of all publicly owned fresh water lakes in such State;
>
> (2) procedures, processes, and methods (including land use requirements), to control sources of pollution of such lakes; and

> (3) methods and procedures, in conjunction with appropriate Federal agencies, to restore the quality of such lakes.
>
> (b) The Administrator shall provide financial assistance to States in order to carry out methods and procedures approved by him under this section.
>
> (c) (1) The amount granted to any State for any fiscal year under this section shall not exceed 70 percentum of the funds expended by such State in such year for carrying out approved methods and procedures under this section.
>
> (2) There is authorized to be appropriated $50,000,000 for the fiscal year ending June 30, 1973; $100,000,000 for the fiscal year 1974; and $150,000,000 for the fiscal year 1975 for grants to States under this section which such sums shall remain available until expended. The Administrator shall provide for an equitable distribution of such sums to the States with approved methods and procedures under this section.

Presumably, compliance with Section 314 will require the establishment of specific standards.

The input model described in Section VI can, under certain assumptions, be used to calculate phosphorus concentrations in a lake and thus be used to determine whether or not a given body of water succeeds in meeting a given standard. The input model calculates the "relative eutrophication" in a lake by dividing the annual g P/year input by the water surface area of the lake (area in m^2) for a series of mean depths (m). If it is assumed that the lake has a mean residence time of one year and undergoes "plug flow" (no mixing), the numerical value of relative eutrophication is equivalent to the mean concentration of phosphorus in the lake (μg P/l). Thus, this allows the estimation of phosphorus concentrations in the lake and comparison to standards assuming that the total annual input is diluted in the lake by the volume at any time and that there is no net loss within the lake (i. e. , deposition in the sediments or outflow); such a formulation is equivalent to a steady state inflow of phosphorus of a conservative substance and is of value only for crude comparative purposes.

2. Land Management Practices for Phosphorus Control From Agricultural Sectors--

Although no conclusive evidence can be cited that fertilizer use is definitely the major source of phosphorus in waterways, one cannot deny that fertilizer usage represents a potentially serious source of pollution, if not properly managed. Since the soil is a natural sink for phosphorus, it can be concluded that essentially all of the phosphorus removed from a soil system is either by crop harvest or surface runoff (erosion) with little loss occurring by internal drainage. The relation that exists between surface runoff, soil erosion, and sediment load of a stream suggests that any management strategy that results in the reduction of surface runoff necessarily reduces the sediment load of streams. In a real sense, the reduction in the sediment load may be of more benefit to society than the corresponding reduction in phosphorus load.

It is a well documented principal that soil erosion, defined as the detachment and transport of soil particles, is best controlled by keeping land under continuous, full cover vegetation, i. e. , pasture and woodland. Any program to reduce phosphorus in surface runoff will necessarily use the concept of maximizing the vegetative cover of land to minimize runoff and soil erosion.

a. Reduction in cultivated acreage--An ovbious control strategy is to reduce the total acreage of cultivated land thus lessening the erosion potential of a given basin. Ideally, this option should be implemented in a manner which does not affect the overall agricultural productivity of a region. To maintain production levels, as marginal cultivated acreage is removed from cultivation, more intensive fertilization and management must be used on the land remaining in tilled crops. The first lands to retire from cultivation should be those with highest erosion potential, that is, land that has a slope of > 3 percent or some internal feature which limits crop growth, e.g., stoniness, shallow soil, drainage, etc. The retired land should be converted either to natural grass or woodland to provide a total vegetative cover for the soil surface and to maximize the organic matter content of the soil, thus minimizing soil detachment. This land will produce revenue in the form of cattle grazing, timber production, and recreational usage, as well as reducing erosion to a level comparable with natural ecosystems.

b. Increased usage of fertilizers as a strategy in erosion control--Increasing the rate of fertilizer application (N and P) on the remaining Class 1 cultivated land is in itself a strategy to reduce erosion and thus P pollution. Maintenance of high soil fertility and productivity is an effective means of erosion control. The production of bumper crops produces maximum ground cover and adds vitally needed organic matter to maintain the infiltration rate and permeability of soils to water. The role of high crop productivity in erosion control is often overlooked. Under intensive production, soil erosion cannot be totally eliminated but it can be reduced to a lower level.

c. Technical management--The strategy of maximizing agricultural production of Class 1 lands to reduce erosion of the resulting P load of receiving water relies heavily on technical agricultural management. For example, chemical soil tests provide an index as to the amounts of P fertilizer that can be effectively applied to the soil in terms of crop response and economic return. A low rating from a soil test may suggest 30-50 kg P/ha can be added to reach a yield plateau whereas a high rating would suggest a low rate of application or perhaps no P fertilization. The frequency and amount of P fertilization must be regulated by crop need. A continuous high application rate of P fertilizer should be avoided since it not only is an environmental hazard, but it is also economically a bad investment. A diligent monitoring program of the phosphorus status of both the soil and the plant is a necessary part of an intensive fertilizer schedule.

Although not recognized generally as an erosion control method, the wide use of fertilizer, manure, and soil amendments can be as effective in preventing soil erosion as many of the traditional cropping and mechanical methods.

Proven cropping methods which reduce sheet and till erosion on cultivated slopes invariably include contour tillage. In this system cultivation is done across the slope rather than with it. If in conjunction with contouring, alternating growing crops such as corn and potatoes with hay and grain in strips is incorporated, the practice is called contour strip cropping. This technique noticeably reduces the velocity of runoff down a slope. When these simpler management techniques are inadequate, terraces can be constructed across the slope. Terraces are generally designed to catch runoff and conduct it away at a gentle slope. Traditional methods of soil conservation have stood the test of time; however, implementation of their usage by individual farm managers remains a barrier.

d. Erosion control using irrigation practices--Runoff from irrigated lands does not contribute significantly to the sediment load of waters. Most erosion occurs from uncontrolled natural precipitation. Since surface flow irrigation systems are designed and developed with reference to the infiltration rate of the soil and since the length of run along with rate of water application is regulated, erosion is generally not a problem in an irrigated agriculture. The general usage of sprinkler irrigation essentially eliminates any surface runoff, even on steep slopes, since the water application rate can be set below the infiltration rate of a given soil. In principle, sprinkler irrigation can be regulated to eliminate drainage output. Irrigation methodology is not considered an important management alternative in P control in waters.

e. Erosion (sediment) control by development of vegetative belts adjacent to receiving waters--This strategy involves land use planning as applied to agricultural lands which border streams. Buffer strips of natural vegetation will be fostered to serve as barriers or filter areas through which all field runoff from agricultural land must pass. In principle agricultural runoff will be treated in these zones to the extent that the sediment load will be reduced to levels commensurate to runoff from natural grass and woodlands. To achieve this goal the zones must be of sufficient width to treat the surface runoff of adjacent fields. It is estimated that a width of at least 200-300 meters would be necessary for buffer belts around major surface streams. This strategy necessarily requires that land adjacent to streams, by virtue of their position, be removed from cultivation. In essence, this amounts to the reduction in cultivated acreage of a given basin requiring more intensive cultivation of remaining land (see D. 2. a).

The buffer zones will be multipurpose. Not only will they abate phosphorus pollution, but they will afford an economic return in terms of livestock grazing, wildlife habitat, and recreational development.

f. Cycling animal manures as a strategy to reduce phosphate fertilizer usage--A strategy to reduce the total P load of waters incorporates the use of less commercial fertilizer by cycling barnyard and feedlot manure back to the field. This strategy is based on the fact that, on the average, 10 tons of feedlot manure has the same phosphorus content as a 100 lb bag of superphosphate (20 percent P) fertilizer. A solution is thus generated for the solid waste disposal problem of animal manure and at the same time the need for commercial fertilizer is reduced. Utilization of feedlot manure also decreases the input of P in surface waters by reducing feedlot drainage which constitutes an important point source of phosphorus pollution. This program can also be applied to sludge and municipal waste disposal problems.

By fluidizing and injecting manure below the surface of the soil or by mechanically incorporating it into the soil, the runoff loss of organic P can be eliminated. At the same time, the introduction of organic matter into the soil greatly enhances the infiltration properties of the soil thereby reducing the erosion hazard. This fact alone is sufficient to endorse the cycling of manure as a major strategy in phosphorus pollution control.

The time of year at which manures are spread is also important in controlling agricultural runoff problems. Usually manures are spread at the end of winter before spring planting constrains the farmer's time. In cold climates this is the worst time of year because runoff occurs immediately after spreading and a larger input with runoff occurs.

The use of land disposal for animal manure is not a new concept in agricultural management systems. However, modern fertilizer technology has made the economics of the use of manure as a source of plant nutrients questionable. In the context of pollution control the economics of land disposal of manure in agricultural operations must be reevaluated.

Summary of Land Management Strategies

The strategies listed above are based on the need to redefine the use of the land resource for the betterment of society. Essentially they involve:

1. Removing erodable land from agricultural production;
2. Intensifying cultivation on remaining land;
3. Creation of vegetative buffer zones adjacent to waterways; and
4. Using land disposal for animal manures to recycle phosphorus in agricultural production.

The strategies constitute the regulation of land use patterns to control the quality of water. The result will be to concentrate productive lands into smaller units with optimal control over fertilizer usage and land management practices, thus maximizing agricultural production while minimizing erosion and surface runoff.

3. Land Use Controls--

Most of the sources of phosphorus identified in the input model are directly affected through land use. It is thus important to review the kinds of land use controls that are available and to indicate the range of application for each.

a. Zoning--A widely used method of controlling land use is through zoning. Zoning practices and theories are so numerous, complex, and dynamic that it would be impossible to give anything but a very general account here. Zoning belongs to statutory law and is based on the police power. In the United States, ultimate zoning authority resides with the states. All the states have enacted enabling legislation which delegates zoning power from the state to counties and municipalities. In recognition of the need for comprehensive regional planning, such power is also delegated to area and regional planning units or is retained by the states. Often, enabling legislation requires that the zoning authority prepare a "plan" for controlling development and land use. The A-95 Circular issued by the Office of Management and Budget and the pending federal land use bills require the states themselves to develop a comprehensive land use "plan" and would have the effect of giving more power to planning units above the municipal and county levels.

Zoning can be used to control overall patterns of development and interrelations among land uses. It can control the nature and intensity of development so that environmental protection, properly scaled public facilities, and other necessities and amenities can be provided.

Zoning in an enlarged planning context--a context which incorporates the natural resource base as well as the concept of rural zoning--may be used to control the input of phosphorus into receiving waters from landfills, development on watersheds, grazing lands, and tilled lands. This technique may be used to preserve green belts or vegetative buffer zones (as discussed under D. 3, Land Management Practices) and to reduce erosion.

b. Licensing--In Legal Study 17 of the National Water Commission (NWC-L-72-043) completed in December of 1971, it was concluded that licensing agencies have authority and an important role to play in protecting environmental values. The study noted that environmental quality standards should be given high priority in licensing, and that environmental impact statements, hearings concerning these statements, and adversary proceedings should all be an integral part of the licensing procedure.

Special commissions (e.g., the San Francisco Bay Conservation and Development Commission) and agencies (e.g., Wisconsin's Consolidated Natural Resources Department) have adopted such a concept of licensing and would be in a strategic position to enforce phosphorus controls. Pending federal land use bills, if adopted, would require federal projects to conform with state land use planning and licensing procedures.

c. Leasing--The above discussion of licensing applies as well to leasing procedures. Grazing lands, land utilized for mining, forests managed by timber industries, recreational and private developments on Forest Service, and other public lands--all potential sources of phosphorus pollution--are activities controllable through leasing procedures.

d. Codes--Through building codes, plumbing codes, minimum housing codes, etc., a planning or regulatory unit can assure that construction on a given parcel of land is sound, safe, healthful, and includes appropriate facilities. To give just one example of how this kind of control relates to the control of phosphorus pollution, a regulatory unit might reguire sealed spetic tanks or else a sewerage system in an area whose surface waters would receive open septic tank leaching.

e. Permits--Section 402 of the 1972 Water Pollution Control Act requires a permit for the discharge of any pollutant from any point source, including publicly owned waste treatment works.

Until the 1972 act was passed, permit granting activities related to water pollution had been administered under the Refuse Act of 1899 by the Corps of Engineers in cooperation with EPA. The EPA now controls this activity until it issues its guidelines to the states and approves the state programs. (On an interim basis, EPA can authorize a state control agency permit program for up to 150 days after enactment or until it approves the state program formally, whichever comes first. Any permit granted under this interim authority is subject to individual EPA review and possible revision.) Permits granted under the Refuse

Act will remain in effect for their term. Applications for permits under the Refuse Act on which decisions have not been reached will become applications for permits under this act.

The state control agency, in operating its permit granting program, must notify the public and the EPA of each application and provide opportunity for public hearing before making a ruling. If granting a permit would affect another state downstream from the permitting state, the downstream state is notified by EPA and has an opportunity to express its views.

Each permit granted by a state control agency must have a fixed term and can be for no longer than five years. It must set forth the applicable effluent and other limitations plus the monitoring requirements needed to demonstrate compliance.

The state control agency will notify EPA of every action it takes on every permit application, including its decision to grant a permit. Even after approving the state agency program, EPA retains the right to review and approve any proposed permit, unless it specifically waives that right at the time it approves the state program.

4. Solid Wastes Management--

Solid waste disposal sites such as landfills and open dumping are relatively unimportant in terms of the overall strategy for controlling phosphorus because little phosphorus in comparison to other sources actually gets into the surface waters except for isolated situations. However, it may be advantageous to control solid waste leachate for other reasons, for example, BOD, nitrogen, and possibly toxic organic chemicals.

a. Disposal regulation--This particular control could be exercised with regard to specific compounds, refuses, or garbages that were high in concentration for particular compounds, in this example, phosphorus. By restricting or segregating their disposal, elimination of their presence in the landfill or open dump could be accomplished. Other disposal regulations would include the kinds of regulations which are now being exercised in controlling open dumps and landfill construction. Building codes and permits which regulate how landfills are constructed and maintained and the elimination of open dumps would prevent many of the abuses which are now occurring. An additional building code to allow the construction of drains for collection of leachates and channelization for runoff waters carrying leachates would allow the possibility of treatment by taking the leachate and returning it to the surface of the landfill to allow it to percolate through the soil. As described previously in Section V, recycling of leachate through the landfill effectively removes most of the phosphorus.

b. Fees--Fees collected specifically to construct landfill, channelization, or drain systems might be appropriate for controlling output from solid wastes facilities. These fees could be based on either the per capita or a mass disposal rate basis. The effect of fees, however, would be minimal because solid waste disposal is a factor which would not be controlled by the use of increasing fee schedules; most studies have indicated that usage of disposable solid waste materials is likely to increase independently of control methods.

5. Effluent Charges--

Application to effluents--These charges are defined as the fees leveled on actual output of the pollutant from a process. Effluent charges are a direct incentive to reduce waste product discharge. The basis for the fee should be the opportunity cost of the pollutant which can be defined as either the cost of cleaning up the pollutant to a satisfactory level or the cost of indemnities to reimburse those who are damaged by the pollutant. The tactic is to set these charges so that the producer has a choice to either clean up or let the pollutant enter the system and pay the charges, whichever is in his interest which, in a free market, would also be efficient to society. Graduated scales may be part of the scheme in developing the strategy. The objective is to internalize all costs to producers so that prices will reflect the true social costs of production and the consumers' preferences for these goods as compared to others. The motive is to change the system of production which produces the waste, or to provide for funds to remove the damaging factor, or to reimburse those who are harmed.

The effluent charge can be assessed in two ways. The first is by continuous monitoring and measuring to determine the exact output to which the level of charge can be applied to arrive at a total payment. The second is by some standard being set which could be randomly monitored. Ordinarily, the administrative costs will be much less with random and occasional monitoring than with continuous enforcement and charges for each unit of discharge.

In geographical locations where several similar activities contribute pollutants to a reach of a stream the costs of cleanup may be lessened by group action through a larger removal plant. In this case, the effluent charge may be reduced to account for these economies of scale, or the group may strive to develop an action to remove the pollutants at some point on the stream and avoid the effluent charge.

One of the problems of utilizing effluent charges in any kind of river basin context is that point sources must be identified. A large number of effluent producers involved, or a diverse set of entry points from a single producer, such as a large landowner, may preclude use of this tactic.

The charge is placed on activities based on the discharge of the offending particular pollutant. This can be assessed on an outflow basis or on a mass discharge basis (mass/unit time). The latter would be the most logical for phosphorus. Because it is based on pollutant output rather than product output or other general measure of activity, this measure may be a most efficient means of control in some cases. It offers alternatives based on efficiency of courses of action. First, the production process may be changed. Presumably, most firms are efficiently organized in their production processes based on costs which are internal to the firm. If discharges of pollutants are priced to the firm then alternate processes which produce less of the offending discharge, or clean the discharge prior to leaving the premises, may become economic.

On the other hand, it may be that the firm would choose to proceed with offending discharge because it may be cheaper to, either individually or as a group, clean the stream rather than change production processes. Finally, it may simply be less costly to indemnify receivers of the pollutants depending on the use made of the water and the costs of the above courses of action. To be an efficient system of operation, the least costly of these options must be made available to the producer, and it must be used by him.

The appropriateness of the system in the several phosphate producing activities is summarized in Figure 35. In many cases special conditions may change these evaluations. The technique can only be utilized where identification, measurement, and evaluation of the opportunity costs can be accomplished.

Notes on Feasibility of Effluent Charges

These notes are based on Figure 29 to which numbers and symbols have been added to form Figure 35. The numbers and symbols show the point of application and the feasibility of effluent charge. The discussion is tied to Figure 35 by the appropriate numbers and explains in more detail the possible problems of applying effluent charges to the particular activity.

1. No control is possible.
2. This source is a balancing variable in the model. Control would be in another basin with all the same phosphorus activities as in the particular basin under consideration.

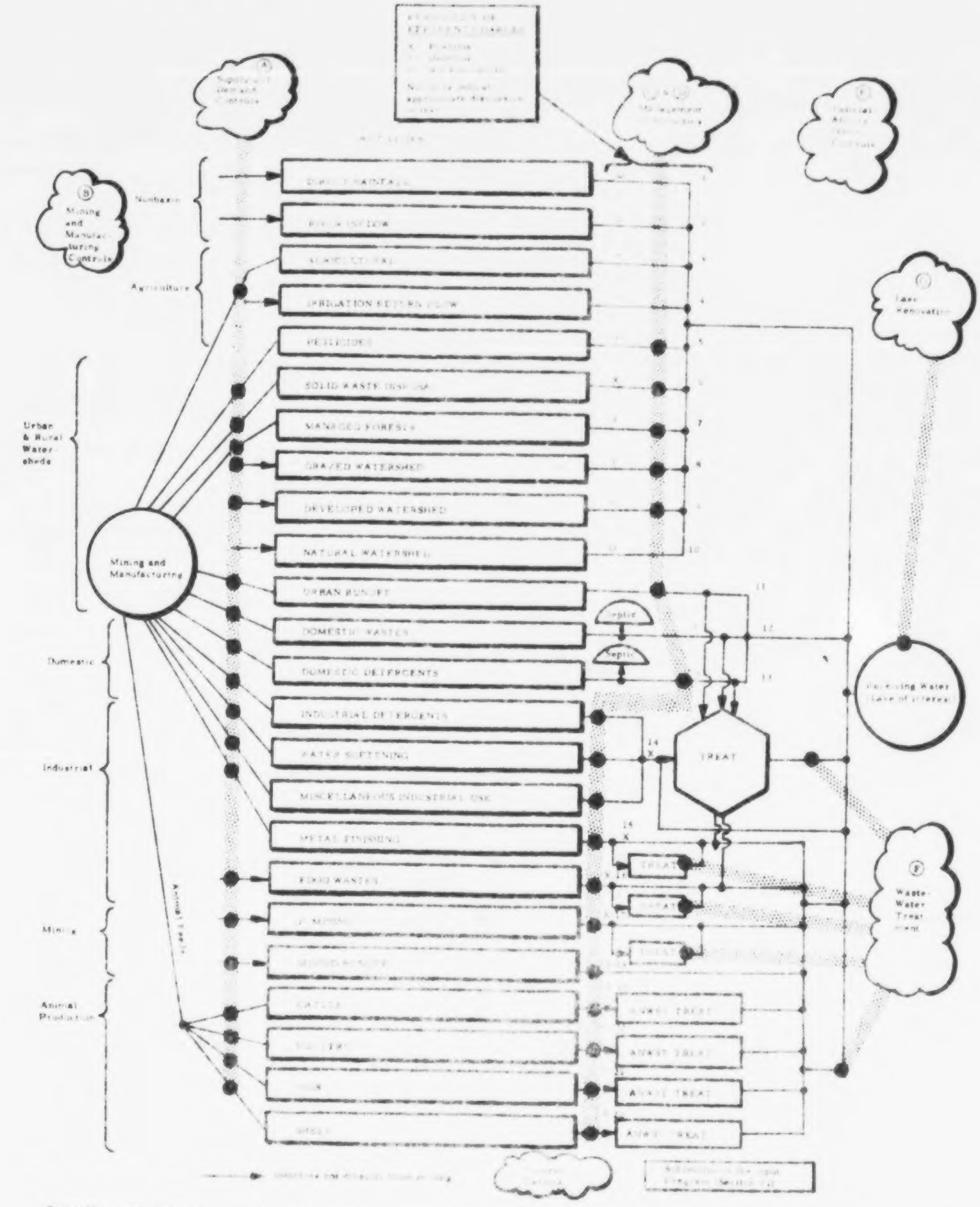

EFFLUENT CHARGES
X = Position
Nonbasin
Agriculture
Urban & Rural Watersheds
Domestic
Industrial
Mining
Animal Production
Mining and Manufacturing Controls
Mining and Manufacturing
Animal Feeds
DIRECT RAINFALL
RIVER INFLOW
AGRICULTURAL
IRRIGATION RETURN FLOW
PESTICIDES
SOLID WASTE DISPOSAL
MANAGED FORESTS
GRAZED WATERSHED
DEVELOPED WATERSHED
NATURAL WATERSHED
URBAN RUNOFF
DOMESTIC WASTES
DOMESTIC DETERGENTS
INDUSTRIAL DETERGENTS
WATER SOFTENING
MISCELLANEOUS INDUSTRIAL USE
METAL FINISHING
FOOD WASTES
MINING
CATTLE
HOGS
SHEEP
Septic
Septic
TREAT
TREAT
TREAT
TREAT
ANAS TREAT
ANAS TREAT
ANAS TREAT
ANAS TREAT
Lake Renovation
Receiving Water (Lake of Interest)
Waste-Water Treatment
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure 35 Control points superimposed on the phosphorus activity analysis [illegible] application points for effluent controls (see pp. 247 [illegible])

3. Sources are extremely diffuse and difficult to monitor in most situations.
4. It requires channelizing to collect flows except in situations involving underground drains, otherwise same as 3.
5. Sources are diverse and usually difficult to monitor.
6. Measurement and identification are not simple. If the desired result is to reduce output of phosphate, this may be ineffective, since the leachates may be difficult to collect.
7. Sources are diverse and may be difficult to monitor in some cases. However, this alternative may be appropriate where few operators are involved in special geographic situations.
8. Same as 7.
9. Same as 7.
10. No control is possible. Sources are diffuse and monitoring is difficult or impossible. It is impossible to define a responsible party.
11. Sources are diffuse. In most cases the charge would have to be levied against the local governmental unit rather than against individual entities. The local government would thus need to devise an allocation system.
12. Since sources are so diverse, it seems impossible to trace the problem back to the offenders. Effluent charges would therefore not likely change the production of effluent, but may provide for equity to those harmed by either paying for treatment, or paying indemnities. Homeowner sewer taxes, etc., are in one sense an effluent charge.
13. Same as 12 because wash products would be included in domestic sewage.

14. These seem to be measurable and industry would have control of the process.

15. The offenders can usually be easily identified. The production system may change and equity served. A note of concern is that other effluent components may be more critical. Possibly a combination of elements need to be monitored and the charges related to the group of pollutants rather than to phosphorus alone.

16. Same as 15.

17. The phosphorus effluent is usually in the form of accidental spills. Thus, continuous monitoring would be required. This method, however, seems to be highly appropriate for control, since it would promote careful management and minimize spills. A system of fines seems more applicable here.

18. Although diffuse, sources are identifiable and feasible to measure. One or few operators can be identified. Maybe a feasible approach for other pollutants, however, may not be socially acceptable.

19, 20, 21, 22. The system may be effective for very large concentrated feedlots or production facilities. Small producers represent diverse sources which are difficult to identify and monitor.

In summary, effluent charges would be an efficient control measure in some cases. This measure focuses on the output of the offending item, rather than on the inputs to the production process, or control of the desirable outputs of goods and services; both efficiency and equity can be served.

6. Bans--

Numerous states and municipalities have placed partial and complete bans on the sale of phosphate detergents. Some examples are:

> New York: Sale of phosphate detergents banned after June 1, 1973, with the exception of incidental concentrations as may be authorized by the Department of Environmental Conservation. The law was modified to exempt cleaning products used in dishwashers, food, beverage processing, etc.
>
> Connecticut: After June 30, 1973, all phosphate detergents are banned with the exception of detergents manufactured for use in automatic dishwashers, and dairy, beverage, food processing, industrial cleaning equipment. This ban was later postponed to June 30, 1974.
>
> Florida: Ban on phosphate detergents restricting to 8.7 percent phosphorus as of January, 1973. Dade County and the City of Kissimmee have total bans.
>
> Indiana: Detergents containing more than 3 percent phosphate are banned after January 1, 1973. Some exemptions for automatic dishwashing products and for some industrial-institutional uses.
>
> Chicago: Ban on the sale of phosphate detergents effective June 30, 1972. This law was declared unconstitutional on March 6, 1973, and is no longer in effect.

Detroit: All phosphate detergents banned after July 1, 1972. This ordinance was preempted by state law which limits phosphorus content in detergents to 8.7 percent.

Considerable litigation has resulted from these statutes and ordinances. The Soap and Detergent Association particularly has filed a number of suits. The litigation has resulted in an evaluation of the bans as reflected in the examples. Arguing that the ban is nonviolative of the Due Process or Equal Protection Clauses of the Fourteenth Amendment, Judge Stevens of the Indiana Supreme Court stated in an opinion C3 ERC at 118, 1120:

> In other words, to put it more directly, if the people of Indiana prefer to wear gray shirts and have a little hardness distilled on their glasses, so forth and so on, as a price for obtaining cleaner water, or for obtaining a chance of having lesser phosphate content which in turn may produce or may not produce, we don't know, lesser amounts of algae, that is a choice which we feel the people of Indiana should make through the Indiana Legislature.

In a similar case but oriented to the particulars of the region where the Chicago detergent control ordinance was struck down, Judge MacMillian of the Northern District of Illinois, Eastern Division, U.S. District Court stated in a decision and order (No. 71 C 1054):

> The evidence of increased costs of manufacture and distribution, however, is relevant to show a burden on interstate commerce. It then becomes the task of the defendant City to justify its ordinance by showing at least some need to protect the public health, safety or welfare....
>
> More to the point, however, is the fact that the Illinois and Mississippi Rivers are so overloaded with phosphates that the removal of phosphates from detergents can have no effect on their plant or fish life....

> This does not mean that similar ordinances in other jurisdictions cannot be sustained, where the effects of discharging phosphates into the public water supply may outweigh the interference with interstate commerce.

Bans could also prove to be effective in agriculture. If it were determined that the soil in a given area is sufficiently rich in phosphorus content that phosphorus fertilization is not needed and/or manure applications could augment soil phosphorus at desirable levels, a ban might be placed on the use (and possibly sale) of phosphorus fertilizer.

E. Judicial Controls

Judicial controls are playing an increasingly important role in the area of environmental management. Judicial review, class action suits, and the common law remedies of nuisance and negligence will be discussed as follows.

1. Judicial Review--

Under the Federal Administrative Procedure Act, a federal court will set aside an agency's actions if they are arbitrary, capricious, abusive of discretion, contrary to the Constitution, in excess of statutory jurisdiction, or unsupported by substantial evidence (5 USCA § 706, 1967). Similar statutes have been established for the review by state courts of state administrative agencies. Although limited review by courts has been the general rule, the process of judicial review seems to be gaining momentum as a significant judicial control in environmental management. In Environmental Defense Fund v. Ruckelshaus (2 E.R.C. 1114, D.C. Cir. 1971), the court stated:

> We stand on the threshold of a new era in the history of the long and fruitful collaboration of administrative agencies and reviewing courts ... (Where) courts (once) regularly upheld agency action, with a nod in the direction of the "substantial evidence" test, and a bow to the mysteries of administrative expertise ... (they now frequently set aside agency actions and require) that administrators articulate the factors on which they base their decisions....
>
> Judicial review must operate to ensure that the administrative process itself will confine and control the exercise of discretion. Courts should require administrative officers to articulate the standards and principles that govern their discretionary decisions in as much detail as possible.

In a comprehensive study entitled Legal Devices for Accomodating Water Resources Development and Environmental Values, Hillhouse and DeWeerdt (1971) stated:

> 9. Judicial review does have a valuable, if limited, role to play. With respect to the (Cross-Florida) Barge Canal, the case filed by the Canal Authority may provide some answers to the troublesome separation of powers question and thereby provide a basis for an improved review system. To the extent that the Barge Canal or other projects are implemented in violation of NEPA or other governing law, courts can avoid environmental damage in particular cases and provide impetus and guidelines for the development of sound projects in other cases.

Environmentalists face serious practical problems, however, when they ask a court to strike the actions of governmental agencies. Some of the practical problems facing potential plaintiffs are: The difficulty of becoming a party or gaining standing, the doctrines of the "ripeness of a case," the doctrine of "exhaustion of administrative remedies," the ability of administrative agencies to shape the development of the record, the fact that "burden of proof" lies with the plaintiff, and the fact that plaintiffs must frequently rely on the voluntary services of legal and scientific experts in long, drawn-out cases. These practical disadvantages have spurred environmentalists to take another judicial avenue, that of class action suits.

2. Class Action Suits--

Rule 23 of the Federal Rules of Civil Procedure states:

> If persons constituting a class are so numerous as to make it impracticable to bring them all before the court, such of them, one or more, as will fairly insure the adequate representation of all may, on behalf of all, sue or be sued, when the character of the right sought be enforced for or against the class is ... several, and there is a common question of law of fact affecting the several rights and common relief is sought.

When a wrong is being committed against a group so numerous that it is impracticable or impossible to bring them all before the court, thus, a class action can be used. As a number of recent cases attest, the wrong in question might involve the savings of a million dollars in abatement costs by a polluter by inflicting a few dollars of damage on each of a million citizens.

A number of states have passed legislation enabling class action to be taken. The Michigan legislation, drafted by Joseph Sax of the University of Michigan Law School, has become a model both for other states and for the Hart-McGovern Bill in Congress. The latter declares that each person has a right to the protection of the environment and that it is in the public interest for Congress to provide adequate remedy to implement this right through class action. The bill is offered as an explicit response to the need for more public participation in decisions affecting environmental values. This bill would sweep away the defenses of lack of standing and would shift "burden of proof" from the plaintiff to the polluter. Section 4 of the bill states:

> When the plaintiff has made a prima facie showing that the activity of the defendant affecting interstate commerce has resulted in or reasonably may result in unreasonable pollution, impairment, or destruction of the air, water, land, or public trust of the United States, the defendant shall have the burden of establishing that there is no feasible and prudent alternative and that the activity at issue is consistent with and reasonably required for promotion of the public health, safety, and welfare in light of the paramount concern of the United States for the protection of its air, water, land, and public trust from unreasonable pollution, impairment, or destruction.

Although the Hart-McGovern Bill may never be enacted (it has been opposed both by EPA and CEQ as well as industry), class action is gaining momentum in various states and has already gained a federal foothold through the Federal Rules of Civil Procedure.

The 1972 Federal Water Pollution Control Act also recognizes citizen suits. Section 505 of this Act states that any citizen or group of citizens having an interest which is or might be adversely affected (as interpreted in Sierra Club v. Morton, 40 U.S.L.W. 4397 (1972)) may, after a 60-day notice, commence a civil suit in the district court against alleged violators of effluent standards or limitations or of orders issued with respect to such standards or limitations by either EPA or state control agencies, except in those situations where the appropriate control agency is already prosecuting the case.

Similarly, any interested citizen or group may commence action against EPA where there is alleged a failure of EPA to perform any act or duty which is not discretionary.

3. Common Law Remedies--

After a potential plaintiff has gained standing in a court, he must plead a claim for which the court has the power to provide relief. Two traditional common law remedies are nuisance and negligence. Each of these remedies have important environmental implications.

Private nuisance--A private nuisance is a civil wrong based on the interference with a property right. Section 822 of the Restatement of Torts has set out the elements of nuisance as follows:

> The actor is liable in an action for damages for a nontrespassory invasion of another's interest in the private use and enjoyment of land if,
>
> (a) the other has property rights and privleges in respect to the use or enjoyment interfered with; and
> (b) the invasion is substantial; and
> (c) the actor's conduct is a legal cause of the invasion; and
> (d) the invasion is either
>   (i) intentional and unreasonable; or
>   (ii) unintentional and otherwise actionable under the rules governing liability for negligent, reckless or ultra-hazardous conduct.

A private nuisance remedy might effectively be sought against feedlots, a principal source of phosphorus pollution in many areas. Precedence for such action might be traced as far back as the decision in 1611 in William Aldred's Case (77 Eng. Rep. 816) wherein it was found that the odor from the defendant's hog sty was a nuisance.

Traditional courts have pursued a "balancing of interests" approach in private nuisance actions. The weakness of this balancing doctrine in environmental cases is apparent, since the powerful polluter will never be stopped unless he injures an equally large economic interest. In Madison v. Ducktown Sulphur, Copper and Iron Company (113 Tenn. 331, 83 S. W. 658, 1904), for example, the court refused an injunction on the grounds that in order to prevent harming farms of little value it would be necessary to close down the plant thus destroying nearly half of the country's tax base and creating massive unemployment. However, courts are tending to view pollution cases in modes other than that of balancing economic losses. An example of this new attitude is found in Department of Health v. Owens-Corning Fiberglass (100 N. J. Super. 336, 242 A. 2d 21, 1968) in which the court held that "it is not unreasonable for the State, in the interest of public health and welfare, to seek to control air pollution. Even if this means the shutting down of an operation harmful to health or unreasonably interfering with life or property, the statute must prevail."

Negligence--Negligence is defined by the Restatement of Torts as conduct which falls below the standard established by law for the protection of others against unreasonable risk of harm. This doctrine has been effective primarily where a single polluter has acted so as to cause specific demonstrable injury to a plaintiff and where the injury is not minor. The doctrine has been ineffective in prosecuting broader public interest cases.

F. Wastewater Treatment

Wastewater treatment at the levels described in Section V can be utilized to remove phosphorus at a central, or several central, treatment plants. Because of the detailed discussion in Section V, it will suffice to say that application of treatment levels can be forced using judicial controls, management policies, standards, and bans (such as zero discharge concepts). The application of fines to municipalities or other treatment districts which have allowed spill type discharges or other "accidental" releases of pollutant to surface waters should, however, be instituted. It seems that many "dischargers" build into their system the possibility for accidental discharge due to overloading, spills, malfunctions, etc. This should not be permitted, and fines should be set up so that such occurrences are minimized and compensation is sufficient.

G. Lake Modification

As described in Section IV, in the amelioration of eutrophication effects in lakes, there are many methods available to restore lakes for such uses (Table 2). Some of the most feasible of these are destratification techniques and precipitation of phosphorus compounds in the lake; deepening (sediment removal) and weed control measures are apparently feasible possibilities.

For certain kinds of lakes, especially those where most of the phosphorus input comes from diffuse and/or uncontrollable sources, lake modification (lake restoration) is probably the most economical approach. What it implies, however, is that a certain amount of eutrophication is permissible at certain levels depending on the costs involved. It is probably not feasible for controlling eutrophication in large lakes or in lakes where the major parts of the input are point sources. Further consideration of lake modification is not within the scope of this report and it is mentioned here primarily as a possibility. Future developments in this field, however, likely will make it an important solution, particularly for areas where there is a low tax base, it is expensive to apply nutrient control measures, or the lake is not receiving wastes of point source nature.

SECTION VIII

COST-EFFECTIVENESS ANALYSIS OF STRATEGIES FOR PHOSPHATE MANAGEMENT

APPROACH TO STRATEGY DEVELOPMENT AND COST-EFFECTIVENESS ANALYSIS

The development and analysis of strategies for management of phosphorus in a river basin require a comprehensive assessment of the magnitude of input sources and a knowledge of the tactics available for controlling the flows from those sources. An in-depth examination of phosphate sources is presented in Sections V and VI and detailed descriptions of management control methods and tactics and points in the flow system where they can be applied are described in Section VII. This section examines the implementation of sets of control methods and analyzes their effectiveness as comprehensive strategies for basin-wide phosphate management.

Using the Phosphate Mass Flow Model

The Phosphate Mass Flow Model for water resource basins described in Section VI (see also Appendices C and D) is used as a basis for testing and evaluating the effectiveness of various strategies for phosphate management. The model operation provides an accounting system for calculating the total phosphorus mobilized in a basin, tracks its flow and loading on the surface water, and computes the potential eutrophication impact of those loadings. The effects of different control strategies are then examined by manipulating the model inputs to simulate the effects of applying reasonable control methods to the phosphorus input activities and determining the change in eutrophication levels.

Coordinating Controls for Management Strategies

The coordination of a set of control methods and tactics for management of phosphate inputs for an entire water resources basin constitutes a strategy. Hence, a strategy consists of the combination of methods that are implemented to control phosphorus flows from the activity systems (agriculture, urban and rural watersheds, domestic, industrial, mining, and animal production) represented in the mass flow model. There are, of course, a very large number of possible strategies which can be constructed from the various combinations and permutations of control tactics, their points of application in the system, and the degree or level of control applied. This section of the report analyzes only a limited number of these which are representative of the range of strategies that could be implemented. The strategies were selected on the basis of more detailed analysis of the mass flow model and best judgment.

For any management strategy to be successful in reducing potential or actual problems of eutrophication, it must be capable of being implemented and operated basinwide. The analysis, therefore, is developed under the assumption that machinery for basin-wide strategy implementation is or can be established.

In applying the strategies to the basins of the case examples, some of the actions which must be cooperatively carried out by political and institutional jurisdictions within a basin are to levy and collect taxes, to construct and operate treatment facilities, to require compliance with specified management practices by producers and consumers, to limit or ban the use of certain products or processes, and to provide appropriate monetary incentives and performance standards for control of phosphate-generating activities.

Analyzing Cost-effective Management Strategies

A comprehensive analysis of strategies for phosphorus management in water would certainly involve consideration of both benefits and costs associated with achieving various levels of phosphorus. Hence, there are two parts of the evaluation problem. Benefits are related to a marginal damage curve which is calculated from the incremented changes in the total damage curve. This shows how much damages increase with each increment in the rate of phosphate discharge, or, conversely, the damages that can be averted by increased control of phosphorus. It is shown by the downward sloping curve in Figure 36. It can be interpreted as showing that damages per unit of phosphorus decrease as concentrations are lowered, or conversely the benefits gained by averting damages decrease as concentrations are reduced. The second curve shows marginal control costs, i.e., the incremental changes in total costs of

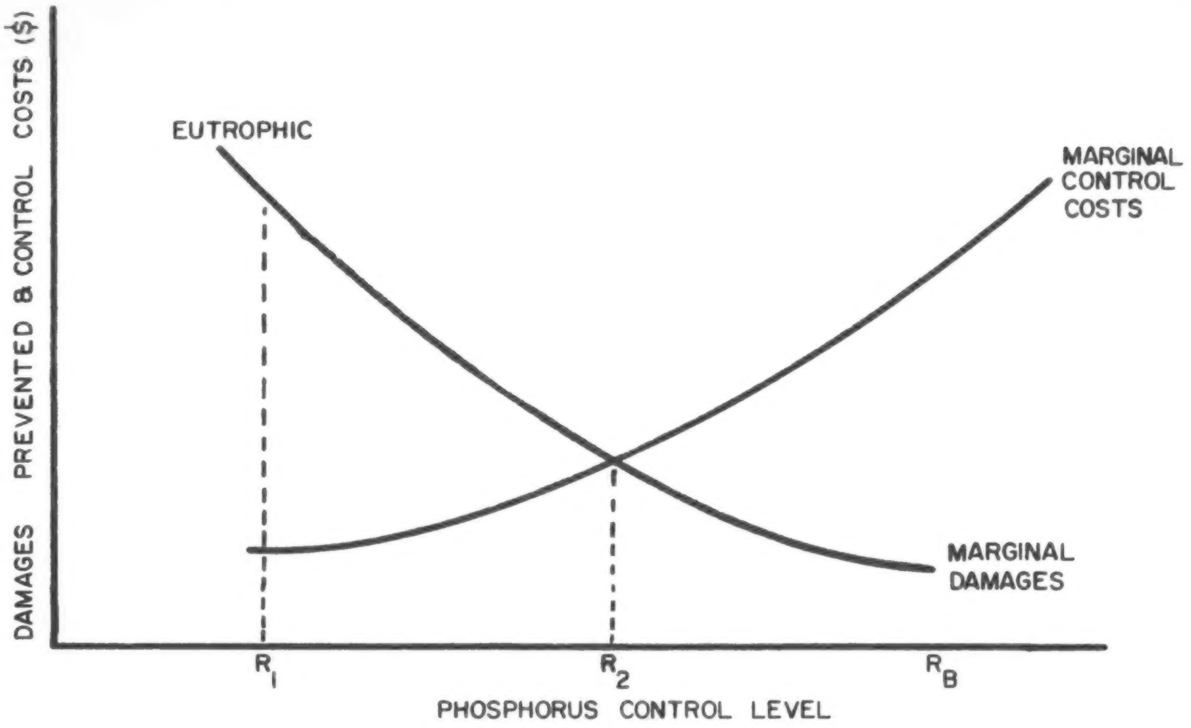


Figure 36. Phosphorus discharges are related to damages and control costs

reducing phosphorus concentrations. As could be expected, the last increments of phosphorus removal become more and more expensive.

Note that cost per unit of control is high in the region of R_3 where most of the phosphorus discharges are averted. The incremental costs are low in region R_1 where little is done to avoid discharges.

To achieve an optimal rate of discharge it is necessary to operate where the marginal control cost equals the marginal damages. This occurs at rate R_2. At R_3 marginal control costs exceed marginal damages. Therefore, a higher level of discharge would be more efficient. On the other hand, at R_1 marginal damages exceed marginal control costs. This implies that more controls should be applied to avert damages.

Since there are no adequate data on the benefits from reduction in discharges, this study is mainly concerned with comparison of alternative control measures based on a criterion of selecting the least cost or most cost-effective control strategy.

In considering only the cost side of the problem, a benefit/cost comparison is needed to test the question of whether the cost is worth the benefits received. It should not necessarily be assumed that control justifies itself, as is often assumed in setting standards. However, cost-effectiveness analysis provides a rational basis for decision given the stated desire or objective of society to achieve an efficient solution to a problem. An overview of benefit-cost and cost-effectiveness analysis as applied to the phosphate flow management system is shown in Figure 37.

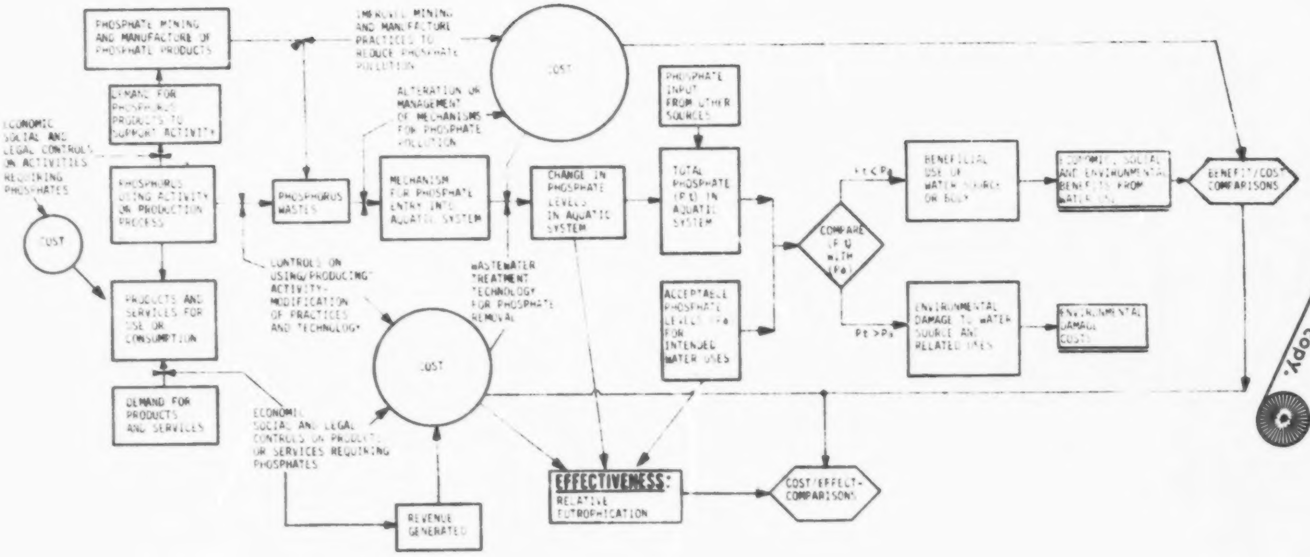

PHOSPHATE MINING AND MANUFACTURE OF PHOSPHATE PRODUCTS
DEMAND FOR PHOSPHORUS PRODUCTS TO SUPPORT ACTIVITY
ECONOMIC SOCIAL AND LEGAL CONTROLS ON ACTIVITIES REQUIRING PHOSPHATES
COST
PHOSPHORUS USING ACTIVITY OR PRODUCTION PROCESS
PRODUCTS AND SERVICES FOR USE OR CONSUMPTION
DEMAND FOR PRODUCTS AND SERVICES
IMPROVED MINING AND MANUFACTURE PRACTICES TO REDUCE PHOSPHATE POLLUTION
COST
ALTERATION OR MANAGEMENT OF MECHANISMS FOR PHOSPHATE POLLUTION
PHOSPHORUS WASTES
MECHANISM FOR PHOSPHATE ENTRY INTO AQUATIC SYSTEM
CONTROLS ON USING/PRODUCING ACTIVITY-MODIFICATION OF PRACTICES AND TECHNOLOGY
WASTEWATER TREATMENT TECHNOLOGY FOR PHOSPHATE REMOVAL
COST
ECONOMIC SOCIAL AND LEGAL CONTROLS ON PRODUCTS OR SERVICES REQUIRING PHOSPHATES
REVENUE GENERATED
CHANGE IN PHOSPHATE LEVELS IN AQUATIC SYSTEM
PHOSPHATE INPUT FROM OTHER SOURCES
TOTAL PHOSPHATE (Pt) IN AQUATIC SYSTEM
ACCEPTABLE PHOSPHATE LEVELS (Pa) FOR INTENDED WATER USES
EFFECTIVENESS: RELATIVE EUTROPHICATION
COST/EFFECT-COMPARISONS
COMPARE (Pt) WITH (Pa)
Pt < Pa
Pt > Pa
BENEFICIAL USE OF WATER SOURCE OR BODY
ENVIRONMENTAL DAMAGE TO WATER SOURCE AND RELATED USES
ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS FROM WATER USE
ENVIRONMENTAL DAMAGE COSTS
BENEFIT/COST COMPARISONS

Figure 57. Cost-benefit and cost effectiveness analysis related to phosphorus mass flow.

Reproduced from best available copy.

In analyzing "cost-effective" strategies, costs are defined as "real" costs, i.e., only those items which divert resources from other productive uses in providing goods and services are real costs. In general terms four kinds of costs are identified as real costs, as opposed to the separate category of transfer payments. Real costs may be imposed on society as a whole as program or administrative costs for governmental units, while the incidence of others usually is at the consumer level, although many are levied at the producer level and indirectly passed on. A more specific description of costs and transfer payments is provided in the following discussion. Also in the accompanying Table 41, the various kinds of costs are associated with the control methods previously enumerated and described in detail as follows:

a. Production Loss--

Actions which diminish the production of desirable goods and services may be among the most promising pollution control mechanisms. This arises because of the production externalities problem, which simply says that production of certain "bads" accompanies production of goods. Thus, an obvious way to diminish production of the pollutants or "bads" is to diminish production of goods.

b. Production Cost Increases--

Production costs can be divided into investment (or capital) costs and operating costs. These are incurred directly by the producing firm, but most evidence would indicate that they are passed on to the consumer, especially if competing firms are faced with the same

Table 41. SUMMARY LISTING OF CONTROL TACTICS

A.	Supply and demand (applies to consumer habits and producer activities)		
	AT	1.	Subsidies (nonphosphorus products)
	AT	2.	Tax breaks and credits
	AC	3.	Price controls
	ATC	4.	Excise taxes or other taxes
	AP	5.	Advertising and education
	AP	6.	Nonmonetary recognition
	AP	7.	Content labeling
	AP	8.	Moral suasion
	ALC	9.	Boycotts
B.	Resource control, mining and manufacturing		
	AC	1.	Requirements for recycling
	ALC	2.	Phosphate mining restrictions (rationing)
	ALC	3.	Manufacturing/production restrictions
	ALC	4.	Emission controls
C.	Management of phosphorus uses		
	ALC	1.	Resource and production substitution
	AC	2.	Technology improvements in processes or uses
	APLC	3.	Monitor requirements with enforcement of application rates (e. g., fertilizer)
	APLC	4.	Recycling and reclamation
D.	Management of phosphorus discharges		
	APLC	1.	Pollution standards
		2.	Land management practices
	AL	a.	Reduction of cultivated acreage
	AC	b.	Increased fertilizer use
	ALC	c.	Technical management
	ALC	d.	Irrigation practices
	AL	e.	Green belts and buffer zones
	APLC	f.	Solid waste recycling
		3.	Land use controls
	AL	a.	Zoning
	ATL	b.	Licensing
	APL	c.	Leasing
	AL	d.	Codes and subdivision regulations
	ATL	e.	Permits

Table 41. CONTINUED

		4.	Solid waste management
	AC		a. Disposal regulation
	AT		b. Fees
	AT	5.	Effluent charges
	AL	6.	Bans
	ATC	7.	Fines
E.	Judicial controls		
	ALC	1.	Judicial review
	ALC	2.	Class action
	ALC	3.	Common law remedies (nuisance, trespass, negligence)
F.	Wastewater treatment--for phosphorus removal		
	AC		
G.	Lake modification		
	APC		

T = Transfer payments
L = Production loss
C = Production cost increases (operating and capital); may be borne by individuals or groups
P = Program cost to governmental unit
A = Administrative costs

requirements and the same operating conditions. Treatment plants attached to an individual firm or to a group of firms or individuals are examples of cost-increasing actions. In most cases, pressure would need to be brought to bear on the firms to bear the increased costs. This pressure may be among any of the general kinds of controls as shown in Table 41.

c. Government Program Costs--

This represents direct actions by government and is, in many ways, comparable to the production costs increases noted. Direct outlays by government are implied in this case, as distinguished from administrative costs defined below. This kind of cost may be most appropriate for overcoming problems in which the sources are difficult to identify, or for other reasons the external effects cannot be internalized to the producer. Since the cost of these government programs represents an alternative to production of other private or public goods and services, they are a true cost as distinguished from the transfer payments.

d. Administrative Costs--

In each kind of program, certain costs of administration for monitoring and supervising compliance will be needed. Personnel costs, instrumentation expenses, and other expenditures will be incurred to enforce conformity to the controls. As with program costs, these are real costs since other goods and/or services could be obtained if these expenditures were not made.

e. Transfer Payments--

These are not real costs since they represent a redistribution of wealth and income from one set of individuals to another. To illustrate, assume that Net National Product is an adequate representation of the income accruing to people in the country. Welfare payments, revenue sharing, and other examples can be cited which shift income from one segment of society to another, but no new wealth is created. Therefore, these transfers do not increase or decrease Net National Product. Note that in Table 41 the control methods with which transfer payments are associated do imply that resources are shifted from one part of society to another. In every case, administrative costs are associated with these transfers and in two cases production losses are implied since with licenses and use permits some controls may be placed on the way in which resources may be utilized.

While the costs described above appropriately belong in the cost-effectiveness analysis, a considerable amount of data collection and analysis is necessary in order to accomplish this. A detailed cost analysis would have to be prepared for each control measure based on a set of specifications for its implementation. The performance of such cost analyses is further complicated by the fact that specifications and therefore costs will depend on the particularities of the basin area being considered. Hence, many of the components of "real" implementation costs for control strategies could not be examined within the scope of this research. In view of this, the cost-effectiveness analysis is approached from the standpoint of "real" costs that are readily available and calculable. These are process costs for treatment of wastewater discharges for removal of phosphorus. These processes and costs are discussed in detail in Section VI, and are incorporated into the Phosphorus Mass Flow Model as a subroutine. The subroutine will accept flows from specified phosphorus activity sources and determine the minimum-cost treatment to achieve a given level of removal. The cost-effectiveness of various management strategies is then analyzed in terms of cost-savings which can be accrued by avoiding the need to apply treatment in order to achieve the same level of effectiveness in terms of relative eutrophication.

The following simple example depicted in Figure 38 serves to illustrate this approach. In the figure a measure of the relative eutrophication of the lake is plotted on the ordinate versus the treatment cost of achieving that level on the abscissa. Two cost-effectiveness curves derived from the P-Mass Flow Model are shown. The first assumes a strategy which relies solely on treatment processes for all phosphorus removal; in the second a set of management controls (a strategy) is applied along with treatment. It is seen from the plot, that the effect of the management control is to reduce the level of eutrophication to R. To achieve the same level through the use of treatment technologies would have a cost of S dollars per year. In terms of selection of a strategy to reduce eutrophication to level R, if the "real" cost of implementation of the management strategy is less than S then it pays to adopt the management control.

Further, if the desired effectiveness in eutrophication level were Q, then the cost-savings of implementing the management controls increases considerably. The cost of achieveing this level through treatment only would be U dollars per year and the cost savings of implementing the management controls in achieving the same level of relative eutrophication, Q, is the amount T dollars per year. In this case the management strategy should be implemented so long as the real costs are less than T dollars per year.

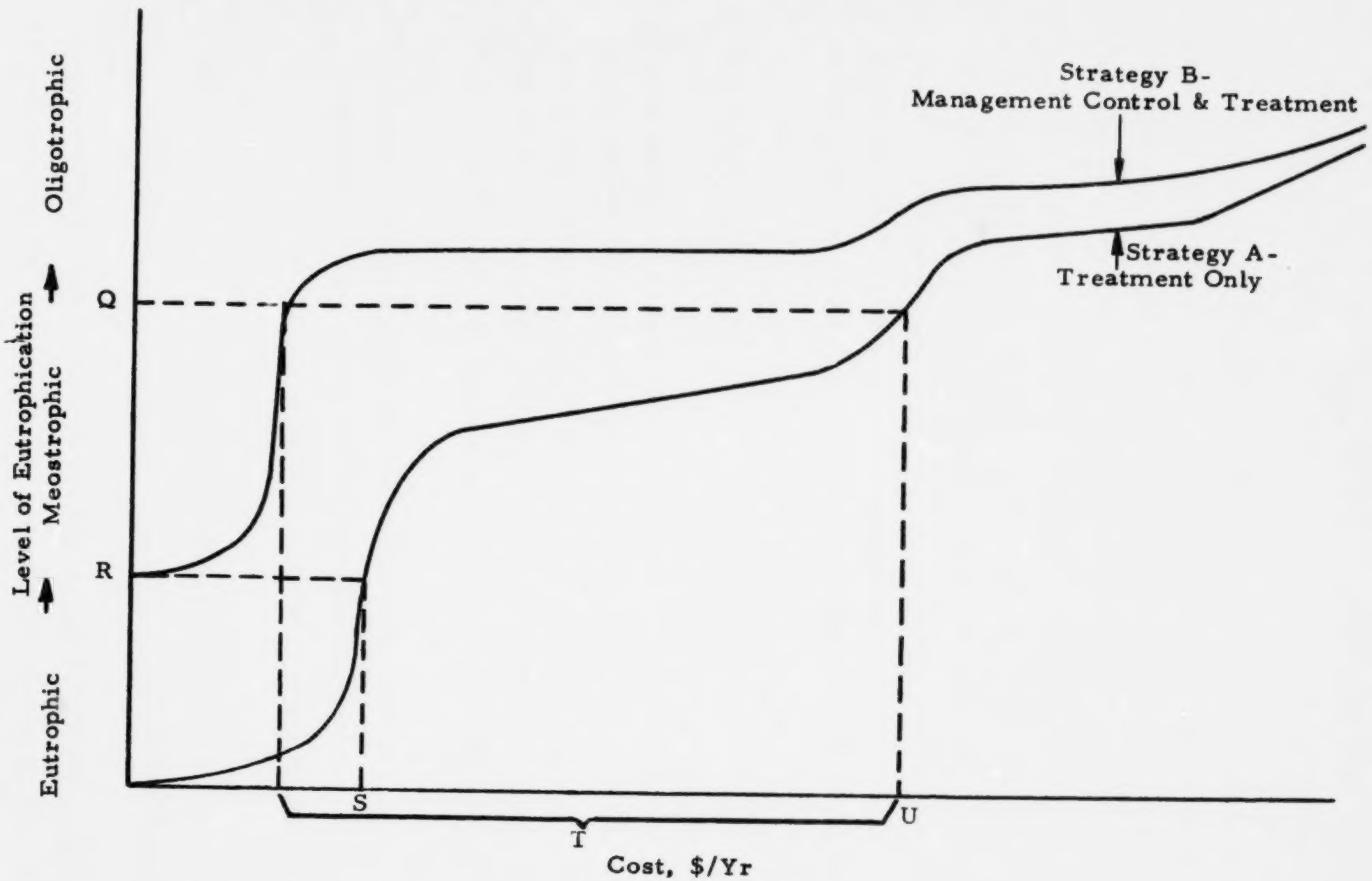


Figure 38. Example cost-effectiveness curves.

To summarize, the application of the Phosphorus Mass Flow Model and treatment subroutine can be used to generate a set of cost-effectiveness curves for comparing alternative management strategies. Given a desired achievement level for which a water body can be maintained in a noneutrophic state, and a decision-maker's estimates of real strategy implementation costs for his particular situation, a cost-effective strategy can be selected. Similarly, if the total program budget is fixed, then a strategy can be selected which maximizes the level of effectiveness. Three case examples are presented in the following to illustrate the model outputs and analysis approach for a real system.

ANALYSIS OF BASIN CASE EXAMPLES

Three case examples of water resources basins are analyzed in order to test the model and analysis concepts. One is a hypothetical basin with the data set made up as necessary to test the model during its development. The others are the Lake Erie and Lake Michigan Basins with the data based on information contained in Appendix D.

The latter two basins provide a basis for examining and evaluating the application of the modeling and analysis procedures for examining phosphate management strategies in an actual setting.

Targeting P-Activities for Application of Control Strategies

The beginning step in the analysis is to identify those activities in the basin that are responsible for the major inputs of phosphorus into the surface waters. To accomplish this, a model run is made for the presently existing conditions in the basin. This established the current levels of P-discharges from each activity and readily identifies those that contribute the majority of the P-loadings on the surface waters. These are the activities that should be attacked in order to control eutrophication. The baseline condition for the three basins, Hypothetical, Erie, and Michigan, are shown in the bar graphs of Figures 39, 40, and 41. The charts show phosphate outputs produced by each activity as a percentage of the total output generated in the basin. For a number of activities within each basin the output level is so slight as to be negligible so these can be ignored insofar as the application of control strategies. On the other hand, major input sources, such as domestic wastes and domestic detergents for Lake Erie, are prime targets for application of a strong and effective set of controls. Using the baseline analysis of the P-discharges of activities in each basin, those activities were selected for the development of specific control strategies. This set of activities for the basins generally includes the major inputs of agriculture, domestic wastes, domestic detergents, industrial detergents, and a collection of minor inputs including other industrial wastes, urban runoff, and animal wastes. The management controls judged to be most effective as controls on these sources are discussed in the following paragraphs. An estimate of their effect in reducing P-outputs is then input to the model in order to examine the cost-effectiveness impact of the strategy.

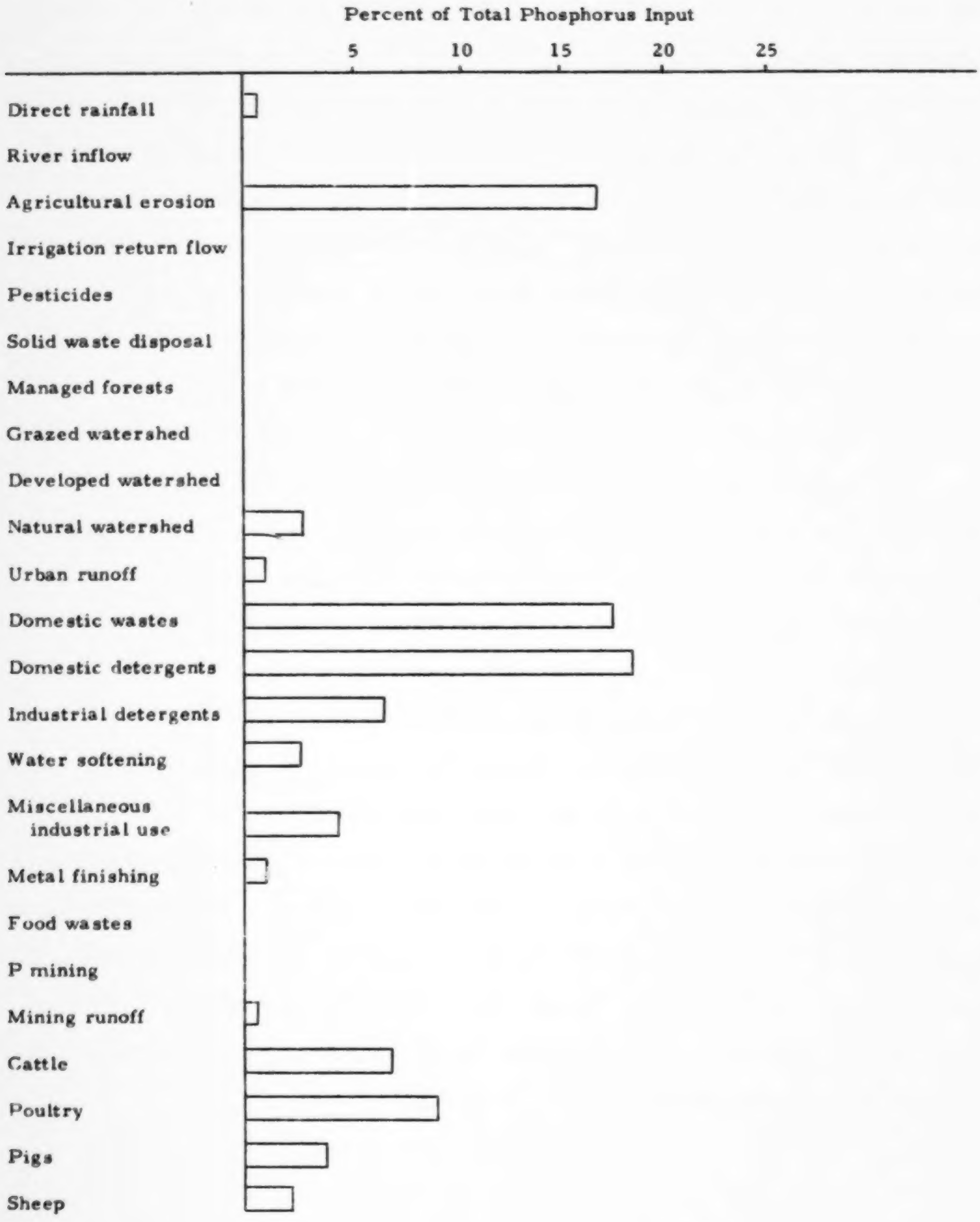


Figure 39. Hypothetical Lake--relative contributions from phosphorus activities prior to application of controls.

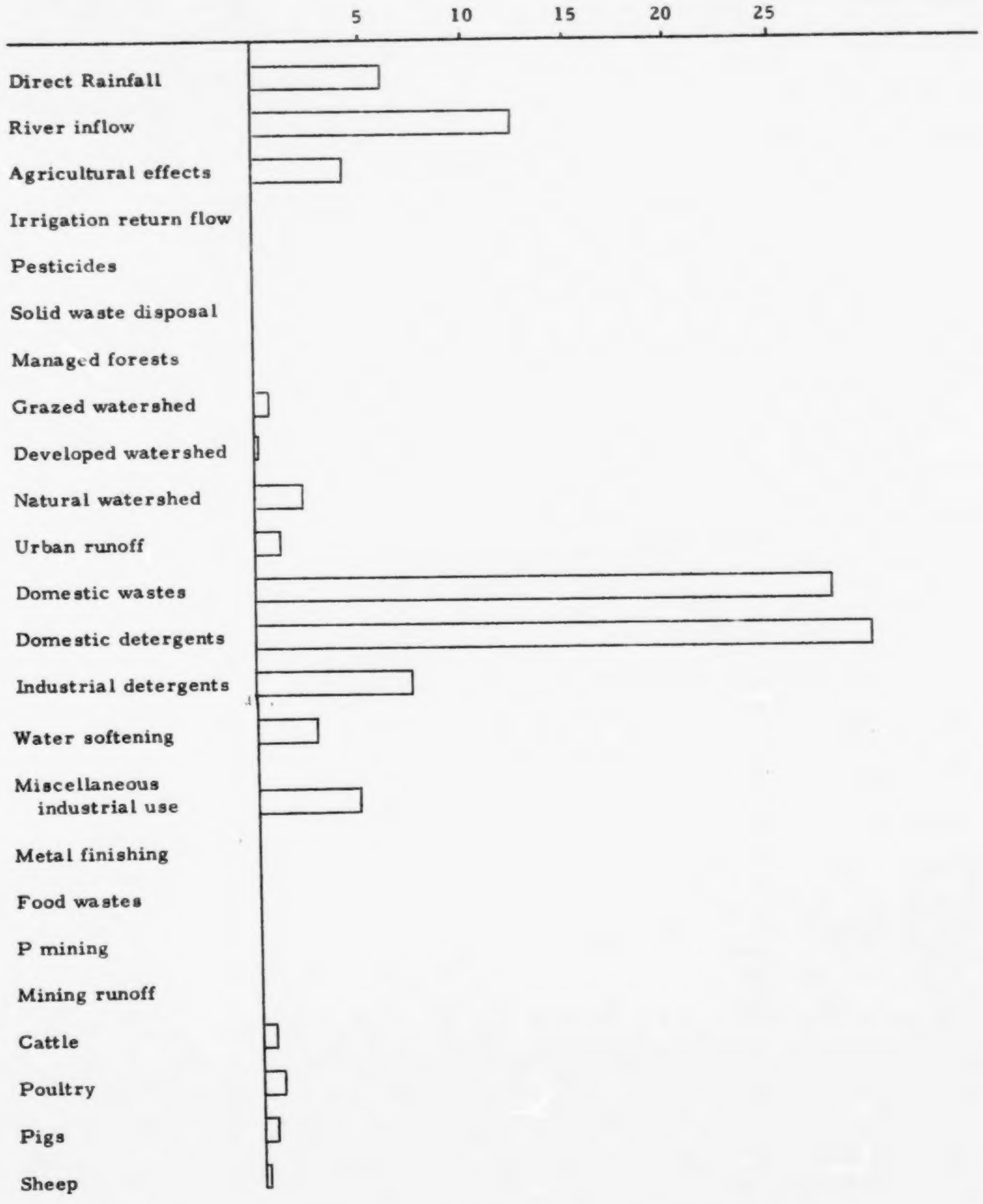


Figure 40. Lake Erie--relative contributions from phosphorus activities prior to application of controls.

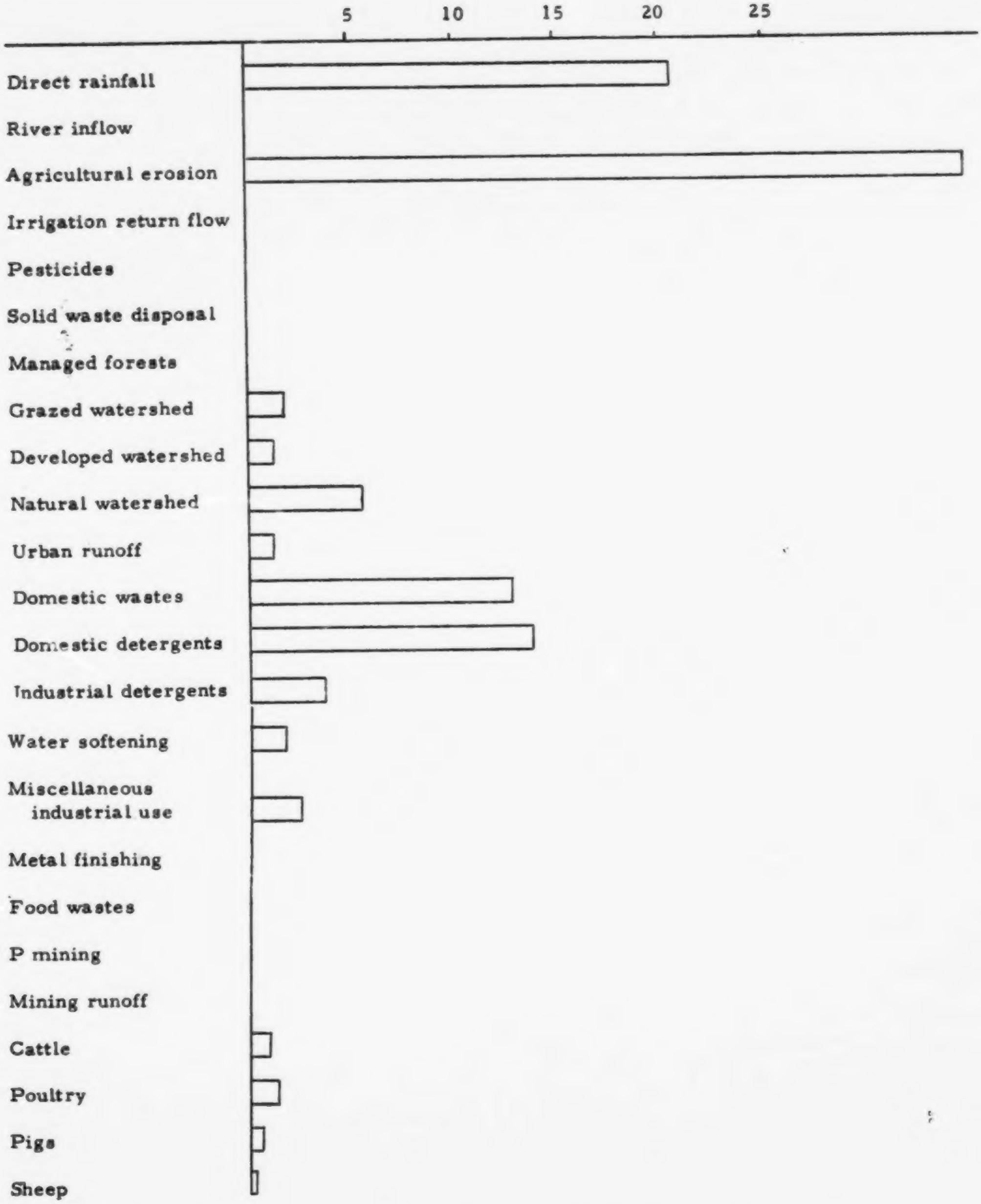


Figure 41. Lake Michigan--relative contributions from phosphorus activities prior to application of controls.

FORMULATING COMPREHENSIVE MANAGEMENT STRATEGIES

Analysis of Mass Flow Program for the Different Lakes

Although the mass flow program was applied to Lake Erie and Lake Michigan without any special adjustments for curve fitting, reasonable agreement with the actual situation was observed. Calculated phosphorus concentrations were about 4 μg P/l for Lake Michigan and 42 μg P/l for Lake Erie. These values compare fairly closely with estimates of about 2-6 μg P/l for Lake Michigan (Schelske and Stoermer, 1972) and 11-90 μ g P/l in filtered water from Lake Erie (Lange, 1971). Thus application of activity analysis and cost-effectiveness to these actual lakes appears reasonable.

After many exploratory runs to determine what kinds of activities should be attacked in order to control eutrophication, a series of strategies were devised. These included treatment of municipal wastes, detergent control, land use management, animal waste controls, fertilizers, and a series of controls for minor inputs.

Treatment of Municipal Wastewaters

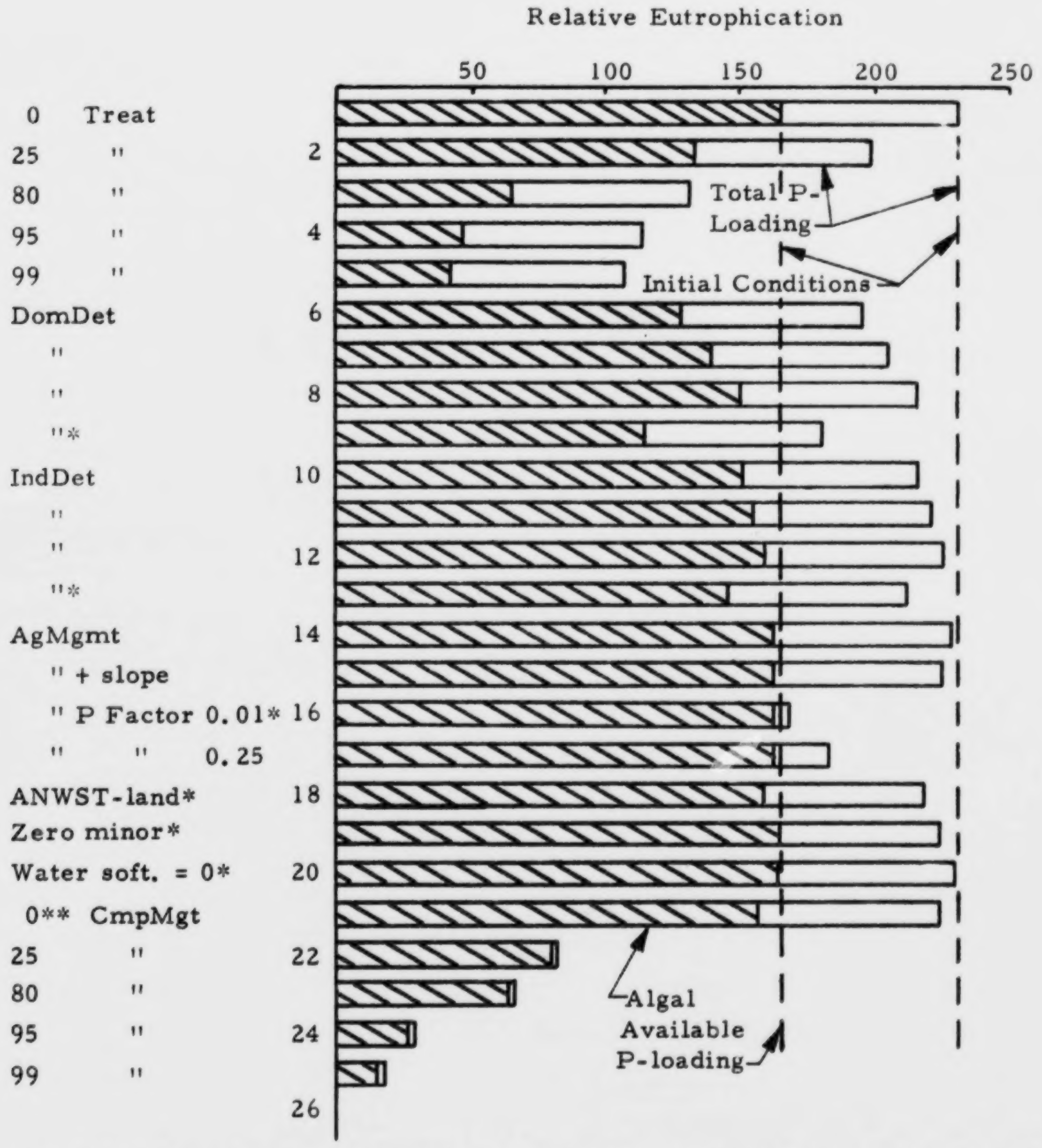
The first series of runs of the mass flow program involved only treatment and no attempt at any management controls. Municipal waste treatment included zero removal (baseline), 25 percent P removal, 80 percent P removal, 95 percent P removal, and 99 percent P removal. Results were obtained in terms of the amount of phosphorus removed and the cost of treatment. Zero removal established the base case from which cost savings are calculated.

The effects of these treatments on the three lakes can be seen in Figures 42, 43, and 44. (Note: The numbers refer to controls applied to the mass flow program.) Numbers 1 through 5 on the abscissa correspond to zero, 25 percent, 80 percent, 95 percent, and 99 percent phosphorus removal, respectively.

Implementation of such controls would most likely be dependent on effluent standards; however, effluent charges, recycling requirements, or judicial actions might precede such standards.

Detergent Control Strategies

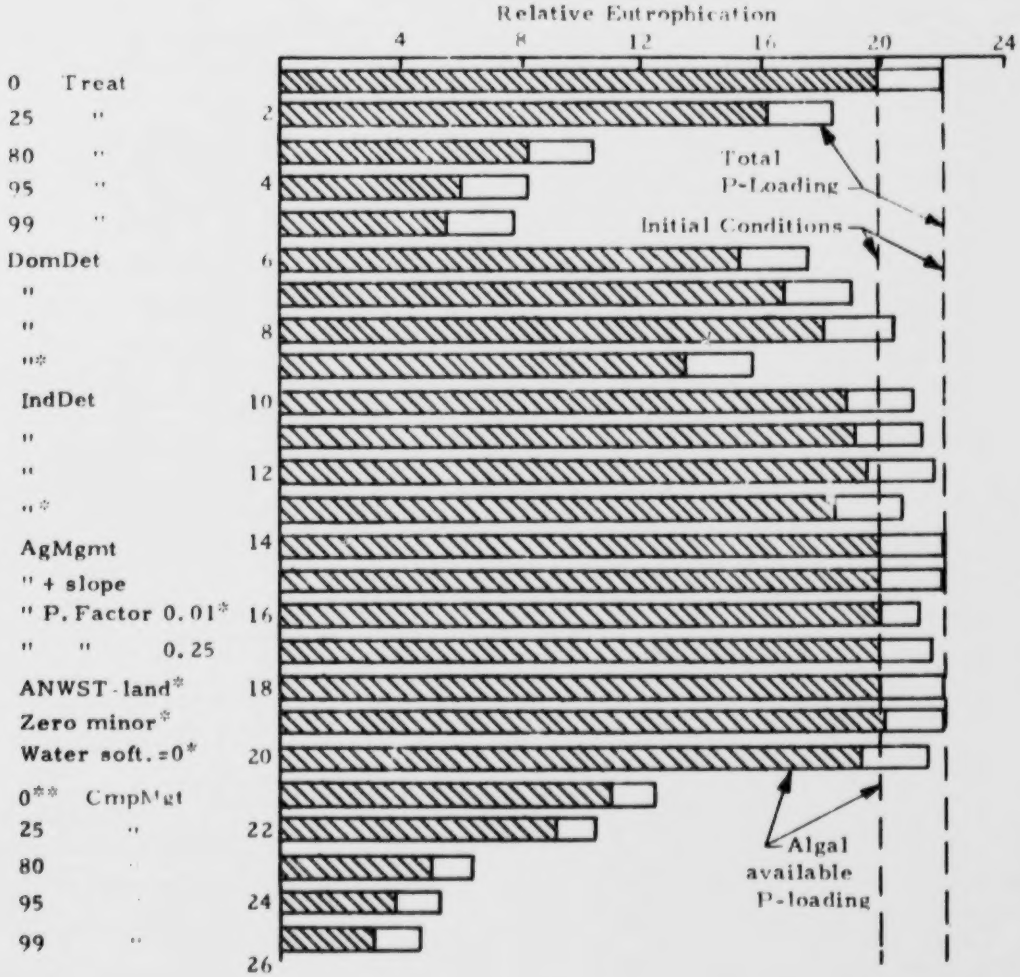
Going back to the situation where no municipal waste treatment was being practiced and no other management controls were applied, detergents were manipulated. In this case, what was done was to decrease the estimated proportion of the population using high phosphate detergent and distribute this use among the other kinds of washing products. It was not material which of the other distributions were utilized, because none of them contributed appreciable amounts of phosphorus. For this case when high phosphate detergent was reduced, the no phosphate detergents and soaps were increased correspondingly in approximately equal ratios. The no phosphate detergent was slightly favored. No distribution to low phosphate detergent was utilized,



*Varied treatment levels were later applied with all these strategies to form CmpMgt. (Note that P = 0.01.)

**Sewered all Ind wastes, urban runoff conc = 0.5 orig.; CmpMgt.

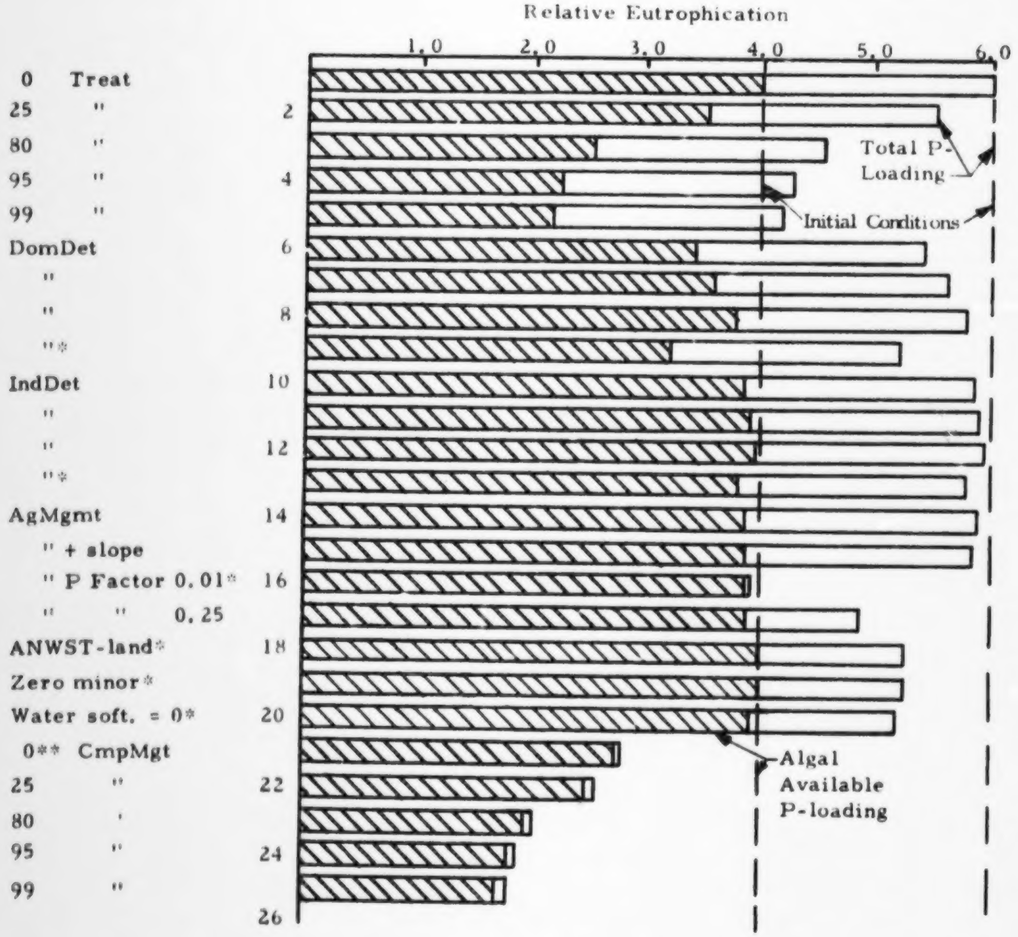
Figure 42. Hypothetical Lake--effects of controls on relative eutrophication (see text for description).



*Varied treatment levels were later applied with all these strategies to form CmpMgt. (Note that P = 0.01.)

**Sewered all Ind wastes, urban runoff conc = 0.5 orig.; CmpMgt.

Figure 43. Lake Erie--effects of controls on relative eutrophication (see text for description).



*Varied treatment levels were later applied with all these strategies to form CmpMgt. (Note that P = 0.01.)
**Sewered all Ind wastes, urban runoff conc = 0.5 orig.; CmpMgt.

Figure 44. Lake Michigan--effects of controls on relative eutrophication (see text for description).

because it was assumed that most regulations applied to detergents would require a level of phosphate closer to zero than low phosphate detergents actually have. Thus, from the initial distribution (Number 1) of 0.7, 0.1, 0.1, 0.1 for high phosphate, low phosphate, no phosphate, and soap, a series of other distributions were made as follows for the respective wash products: (Number 6) 0.2, 0.1, 0.35, 0.35; (Number 7) 0.35, 0.1, 0.3, 0.25; (Number 8) 0.5, 0.1, 0.2, 0.2; and (Number 9) 0.0, 0.1, 0.5, 0.4. A similar approach was taken with industrial detergents; it was assumed that low phosphate detergents would not be used in industrial applications. In this case the initial levels (Number 1) were 0.9, 0.0, 0.0, and 0.1. The series of changed use distributions were: (Number 10) 0.25, 0.0, 0.35, 0.4; (Number 11) 0.45, 0.0, 0.25, 0.3; (Number 12) 0.65, 0.0, 0.25, 0.1; and (Number 13) 0.0, 0.0, 0.6, 0.4.

As can be seen in Figures 42, 43, and 44, significant effects on eutrophication levels were seen for domestic detergent controls (DomDet) but not for industrial detergent controls (IndDet); this results because of different use ratios in the two areas of society (Table 9).

Implementation of controls to produce the above effects has begun already in certain areas of the USA (see Section VII). Likely controls other than the bans already used would include supply and demand controls, particularly excise taxes, and product substitution. (For discussion, see Jenkins et al., 1972.) Costs of such controls are not easily computed because of the difficulty in estimating development costs, possible costs in changing washing machines or other processes to match the products, consumer acceptance, cleaning levels, etc. Analysis of such costs and other management costs should be performed to have a complete picture of phosphorus cost-effectiveness controls applied to detergents. Discussion of excise taxes applied to detergents as introduced in Section VII, occurs further on in this Section.

Land Use Management Strategies

In this case there were four succeeding steps. First (Number 14), soluble available phosphorus leached from agricultural lands was reduced to zero (AgMgmt). This kind of control could be brought about by green belt legislation and by other types of phosphorus removal programs, e.g., increased natural or cultivated vegetation. The second step (Number 15) was to eliminate all highly sloped land (AgMgmt + slope); only Class A (the 0-1 percent slope) land was utilized; the others were taken out of production. At the same time as the second step, the soluble available phosphorus was kept at zero. Such a control measure likely could be brought about by subsidies, zoning, land bank requirements, etc. The efficacy of such control measures in farming sociology and the relative proportion of prime farm lands in the U.S. which fall into this category as well as a consideration of domestic and export needs for farm products is unfortunately unknown. Further analysis of these questions would be necessary before suggesting the implementation of such control measures.

The third step (Number 16) was to keep the first two management steps and to change the practice factor to 0.01 (AgMgmt + slope + P factor 0.01). This is assuming a high degree of competence in controlling runoff and erosion rate. In later analyses the minimum practice factor utilized was 0. 10. By using sprinkler irrigation, careful use of ground cover and developing large green belts, etc., it might be possible to reduce runoff to that particular point for sediments. A reason for doing this lies not necessarily in controlling phosphorus, but in controlling the major problem of suspended sediments and other eroded materials. The fourth step (Number 17) was a less drastic one than the third step, and this was to use a more reasonable practice factor of 0. 25 and all other controls as in the third step (AgMgmt + slope + P factor 0. 25). Similar control measures could be implemented to achieve the effects seen in Figures 42, 43, and 44.

Except for erosion control, little effect on eutrophication was seen. In fact, very little effect in comparison to the zero treatment eutrophication level (Number 1) could be seen for available phosphorus eutrophication levels. This observation reflects the decision that in general phosphorus or eroded soils are not available for algal growth in natural ecosystems.

Animal Wastes Control

In this step (Number 18) it was assumed that the most logical and feasible thing to do would be to require that all animal waste be disposed to lands and that the land disposal should be done in a fairly competent way so that direct discharge of wastes into surface waters could not occur (ANWST-land). Subsidies, effluent charges, land management practices, and bans and fines could be used to implement such control measures. In addition, a requirement that feedlots not be allowed to locate near a watercourse, or be required to move away from watercourses, would prevent most accidental spills. Also, requirements that the application of manures to lands utilize good erosion control practices and that green belts be utilized would minimize land runoff.

The runoff factor from lands obtaining animal waste was assumed to be about 5 percent. This is the maximum value that Vollenweider (1968) suggested for animal manures phosphorus runoff. It is also the level estimated by Biggar and Corey (1969) for frozen land runoff of animal manures in the Lake Mendota watershed. The effect of this control seemed somewhat significant for Lake Michigan (Figure 44) but not for Lake Erie (Figure 43).

Other Miscellaneous Control Devices

Fertilizer application rates were maintained at a relatively low value (10 kg P/ha·yr) because of their effect on eroded material and its concentration of phosphorus. The level chosen was one which would maintain phosphorus levels in the solid phase phosphorus, but which would not cause the eroded phosphorus to increase significantly. Another control was to cause all minor inputs to be zero (zero minor). These could be accomplished by a variety of tactics. The minor inputs were: Irrigation return flow, pesticide runoff, solid waste runoff, and strip mining runoff. In some cases these values were already zero because it was assumed that the particular activity did not occur in the basin, e.g., strip mining runoff in Lake Michigan. Solid waste runoff can be minimized by recycling the leachate to percolate through the overlying soil in the landfill. Phosphorus pesticides runoff can be minimized by utilizing different pesticides or applying pesticide during the low runoff season of the year. Irrigation return flows can be collected and removed from input to natural surface waters: (1) Bypass the lake of interest; and (2) treat for salinity and/or nitrate removal as has been practiced in California (Brown et al., 1971).

Thus, these minor inputs can easily be minimized; they were zeroed in this case. The application of all these controls resulted in the changes noted in Number 19.

A last minor input concerns the use of phosphorus-bearing water softeners in industrial uses. Because of the advent of organic water softening compounds, the amount of phosphorus-based water softeners has remained the same since 1958. However, there is also the possibility that the phosphorus-based water softeners can be eliminated entirely by use of bans or other such controls. This control (water soft. = 0) was added to control of minor inputs and produced a negligible effect in all cases (Number 20). Therefore, it seems reasonable to let water softening phosphorus use disappear without application of controls.

Application of Comprehensive Strategy and Municipal Waste Simultaneously

The next step was to apply the different control strategies to produce a certain desired result in terms of eutrophication of the lakes. These were determined with the hypothetical lake system first and then applied without further experimentation directly to Lakes Michigan and Erie. The first step was to select the particular strategies, and these were:

(1) To ban use of high phosphorus detergent, both in the domestic and industrial use patterns; (2) apply land use controls so that practice factors brought about by various kinds of green belts, etc., would reduce erosion rates to 0.10 of the initial, to eliminate the high-slope lands ("greater than one percent") and to eliminate soluble surface phosphorus runoff; (3) animal waste was shunted to land disposal and 10 kg/ha·yr was the maximum level of fertilization allowed; (4) all industrial waste was required to go through the sewage treatment plant: Thus direct discharge of wastes to streams was prohibited ("zero discharge"); by eliminating certain kinds of runoff conditions and minimizing phosphorus use in road deicing compounds, and in home garden use, the amount of phosphorus coming from urban runoff was cut in half; and (5) all minor inputs and water softening were reduced to zero. Then, using this rather comprehensive strategy (CmpMgt), the levels of treatment were applied as in the first condition (Numbers 1-5), i.e., 0 percent removal (Number 21), 25 percent (Number 22), 80 percent (Number 23), 95 percent (Number 24), and 99 percent (Number 25) removal were practiced. The results of all these applications of strategy to the mass flow model were dramatically improved over any single strategy--especially for the hypothetical lake (Figure 42) and Lake Erie (Figure 43).

Cost-Effectiveness Analysis of Strategy Implementation

The cost-effectiveness analysis of implementing the final set of control strategies, screened out as being potentially most effective, is developed along the lines suggested in the example analysis at the beginning of this section (Figure 38). Data for the cost-effectiveness curves are generated by a series of model runs which simulate the effect of the management control together with wastewater treatments specified for the levels of 0, 50, 60, 70, 80, 84, 86, 88, 90, 92, 93, 94, 95, 96, 97, 98, and 99 percent removal of phosphorus. For each percentage of phosphorus removal, a eutrophication level and treatment cost are computed. The eutrophication level is measured by the indexing number previously discussed, where the smaller the index number, the less the eutrophic condition of the water body. Costs are in dollars per year. These two values, then, determine a point on the cost-effectiveness curve for that management strategy. The collection of points plotted for the range percentage removals generates the entire cost-effectiveness curve for the strategy.

The set of cost-effectiveness curves for the three case examples are presented in Figures 45, 46, and 47 for the Hypothetical, Lake Erie, and Lake Michigan basins respectively. The final set of management controls analyzed were the same for each case. The strategies identified by the phosphorus sources to which they are applied are noted below for ease of reference in the following discussion:

1. Treat- Treatment processes are applied to all phosphorus inputs from sources which can be treated. This establishes the base case from which cost savings are calculated.

2. DomDet- Use of domestic detergents is shifted or eliminated through management controls.

3. IndDet- Use of industrial detergents is shifted or eliminated through management controls.

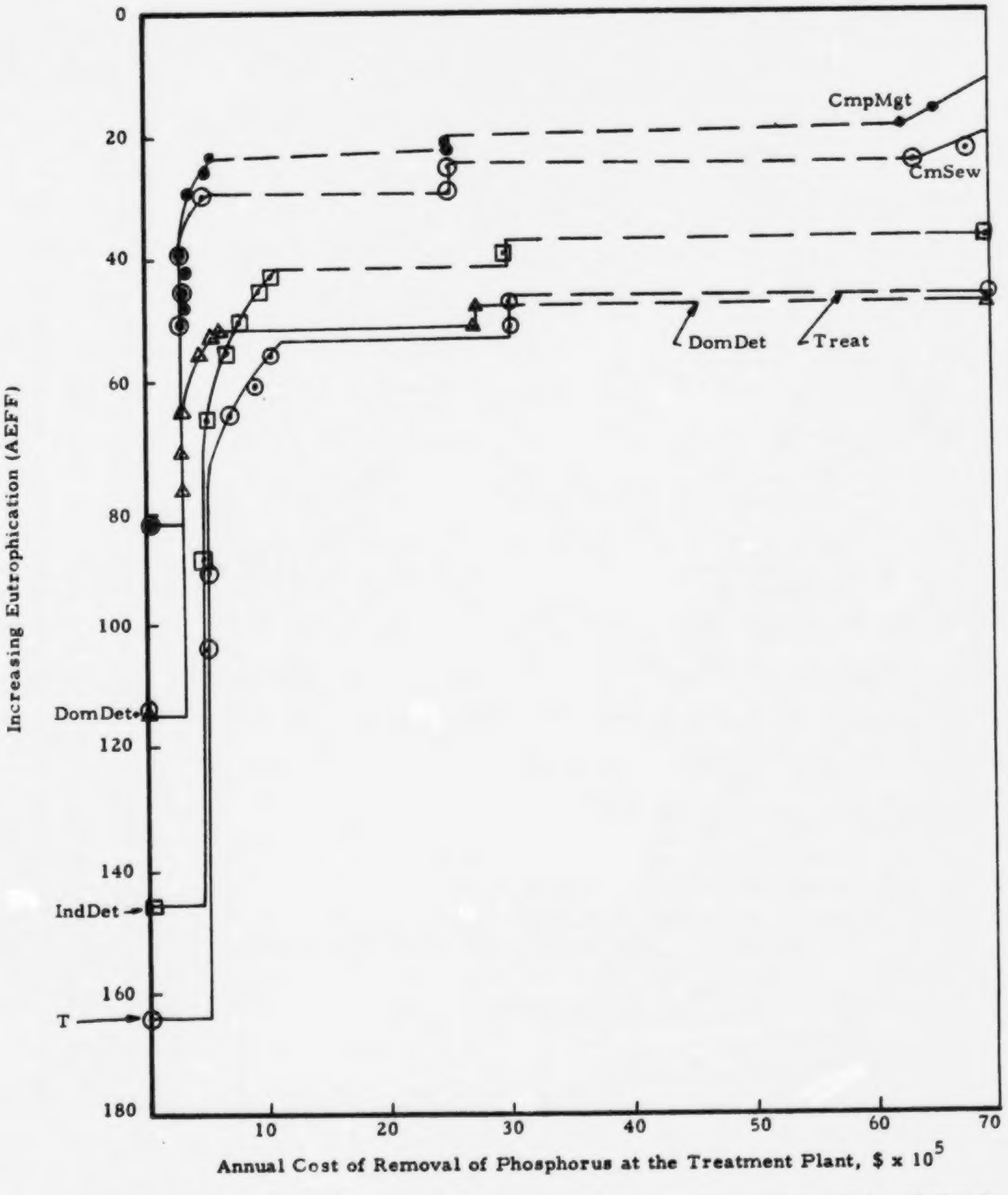


Figure 45. Hypothetical lake--cost-effectiveness of various treatment levels in relation to eutrophication based on available phosphorus loading.

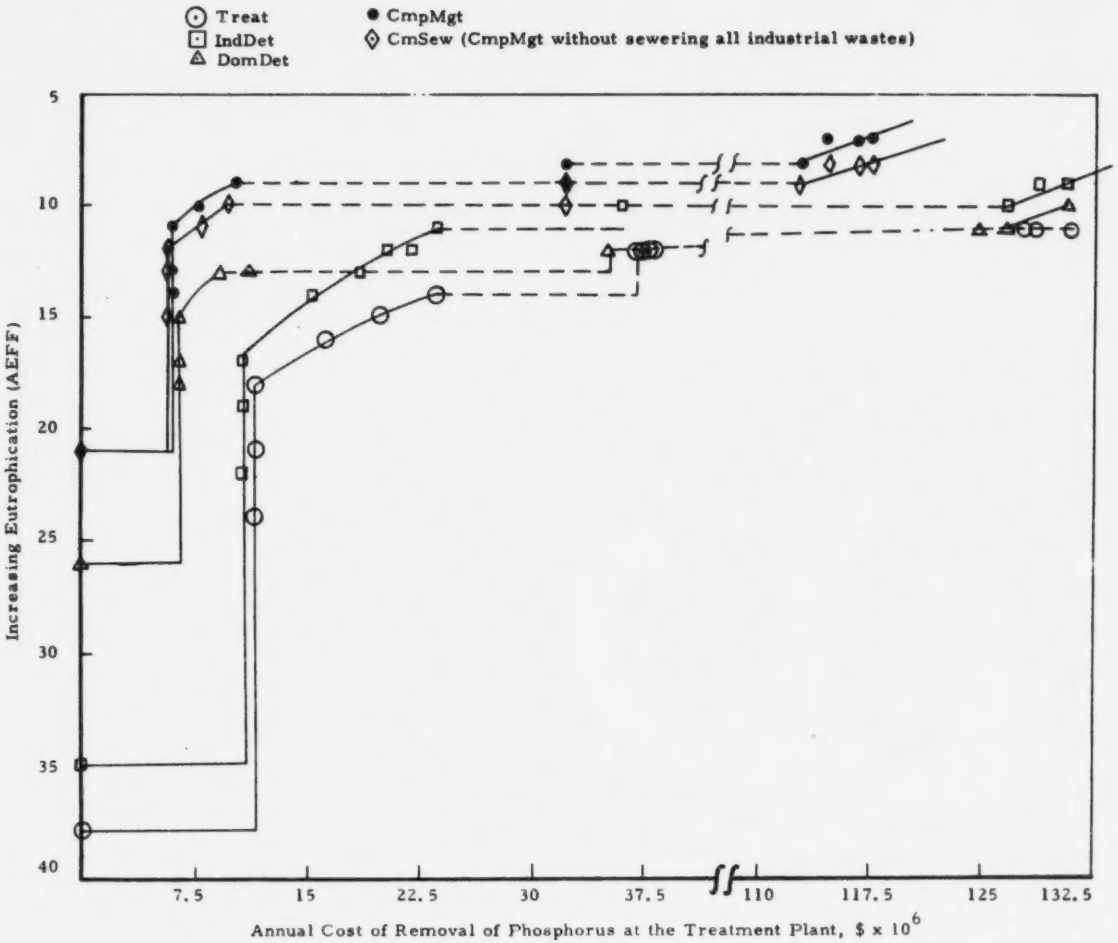


Figure 46. Lake Erie (20 m mean depth)--cost-effectiveness of various treatment levels in relation to eutrophication based on available phosphorus loading.

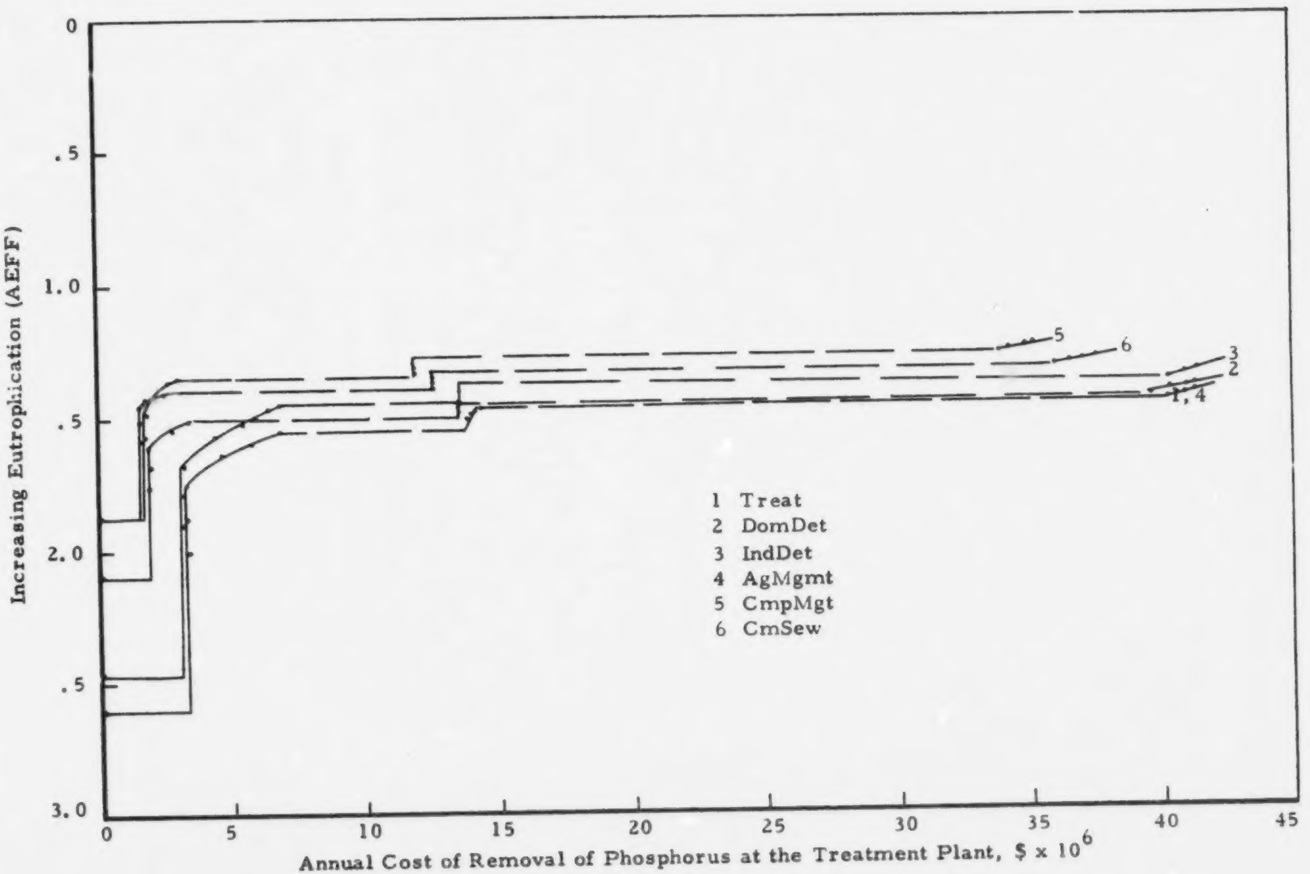


Figure 47. Lake Michigan--cost-effectiveness of various treatment levels in relation to eutrophication based on available phosphorus loading.

4.	AgMgmt-	Agricultural practices are altered in accordance with prescribed management controls.
5.	CmpMgt-	Comprehensive management controls applied to all major and minor input sources.
6.	CmSew-	Comprehensive management controls applied to all major and minor inputs except the required sewering of all industrial wastes.

A general conclusion which can be drawn from the curves for all three cases is that increased effectiveness of treatment processes can be obtained at lower cost by first applying management controls to sources in order to reduce phosphorus loadings. This, of course, was expected and confirms the validity of using the concept of cost-savings, or avoidance of treatment costs, as the basis of a decision rule for determining whether a management strategy should be implemented. To restate the criterion: If the real costs for strategy implementation are less than the treatment costs saved (or avoided) then the strategy should be used.

In addition, a few other general observations about the cost-effectiveness curves should be made. First, AgMgmt evidences no effect on the system since its cost-effectiveness curve corresponded identically with the Treat strategy. Hence, this control strategy does not appear on the cost-effectiveness plots. The reason, however, is due to using eutrophication numbers calculated from the phosphorus available for algal growth rather than total phosphorus residual in the system for the measure of effectiveness (see p. 54ff for discussion). AgMgmt does effectively reduce total phosphorus, but mostly in the forms that are not considered available to algae.

Second, each cost-effectiveness curve reflects segments of cost functions from three different treatment processes, namely coagulation, ion exchange, and reverse osmosis. The treatment subroutine selects the minimum cost treatment process based on constraints which specify acceptable influent concentration and the effluent concentrations which are obtainable in the process. When a higher level treatment process is selected, such as ion exchange or reverse osmosis, there is a discontinuity in the cost-effectiveness curves (shown by the dashed line) which reflects the substantially higher cost function of the higher level process.

Finally, the general picture from the cost-effectiveness curves of impact of the management strategies for the three basin examples appears about the same. The specific conclusions for each basin, however, are quite different because of differences in the initial conditions of relative eutrophication in the lake and in the constituent phosphorus sources of the basin.

SPECIFIC CONCLUSIONS OF MANAGEMENT STRATEGIES APPLIED TO THE INDIVIDUAL LAKE BASINS

Hypothetical

The hypothetical basin is only briefly discussed since it is primarily of academic interest in developing and testing the mass flow model. In the hypothetical case, the lake size is small relative to the size of the basin inputs; hence, the phosphorus loading rate is very high, and consequently, the relative eutrophication. As the cost-effectiveness curves indicate, CmpMgt is required together with reverse osmosis treatment to approach the acceptable range of 5-10 for relative eutrophication. The annual cost for treatment alone under such a program would be $7-8 million. Furthermore, the curve indicates that relatively little effectiveness is gained in going from coagulation at an annual cost of $600,000 and relative eutrophication of 25-35 to reverse osmosis with an annual cost of about $7,000,000 and relative eutrophication of 10-15. Whether or not these very high expenditures would be justified where actual improvement seems doubtful is a question that would need careful study.

Lake Erie

Lake Erie presents an interesting case where a combination of management controls and treatment processes can, in fact, reduce the relative eutrophication levels to within an acceptable range of 5-10. Here, a more detailed examination of the cost-effectiveness curves for the various management approaches can yield further insight into an appropriate course of action.

An initial question is what costs would be justified in the implementation of strategies to control a particular pollutant source? According to the stated decision rule, this must be answered in terms of the treatment cost-savings anticipated. These cost-savings are easily derived from the cost-effectiveness curves. Using, for example, the Lake Erie case shown in Figure 46, calculations summarized in Table 42 are made in the following way. The relative eutrophication for the system with no management or treatment is 38. With CmpMgt, which implements all management options, relative eutrophication is dropped 17 points

Table 42. COST SAVINGS ATTRIBUTABLE TO STRATEGIES FOR LAKE ERIE CASE

Strategy	Relative eutrophication	Change eutrophication	Total % change for management strategy	$ savings attributable to strategy
System is as	38	--	--	
CmpMgmt	21	17	100%	$11.5 m
IndDet	35	3	18%	2.0 m
DomDet	26	12	70%	8.1 m
Combined IndDet & DomDet		15		
All Other		2	12%	1.4 m

to 21. At a relative eutrophication level of 21, cost of the Treat strategy is $11.5 million. The treatment cost-savings attributable to CmpMgt if implemented is $11.5 million. Therefore, it pays to apply a CmpMgt strategy if the total cost of doing so is less than $11.5 million. The proportion of those savings due to the IndDet and DomDet strategy components can also be calculated assuming they are in the same proportion as the percentage of the total change in relative eutrophication that they contribute. The assumption of linearity and superposition seem reasonable since there is little interaction among the subsystems, and a specific drop in relative eutrophication can be associated with particular substrategies included within CmpMgt. Thus, DomDet is responsible for 12 of the total 17 points change or 70 percent. The treatment cost-savings due to the DomDet strategy, then, are 70 percent of $11.5 million, or $8.1 million, and hence it pays to implement the DomDet strategy if it costs less than this. Similar reasoning applies to IndDet and the remaining strategy components.

In applying cost-effectiveness analysis, the selection of an action strategy should be approached from the standpoint of the desired level of effectiveness and of the constraints on available budget. For example, consider a policy objective to achieve an effectiveness level of less than 10 in order to ensure noneutrophic lake conditions. The cost-effectiveness curves of Figure 46 indicate that the management options can produce significant cost-savings at this level. The curves show that a eutrophication number in the range of 10, if it is attainable under Treat at all, can only be achieved with reverse osmosis at a cost in the order of $132 million. Using CmpMgt plus treatment by coagulation a level of 10 is attainable for a cost of $9 million. For this specific level of effectiveness, then, the net savings in treatment cost from CmpMgt is some $123 million. This amount is an upper limit on costs of implementing CmpMgt and any implementation cost less than that represents a net cost-savings.

Even though management may desire to achieve a high level of effectiveness, it is often constrained by budget limitations on what it actually can do. It is also worthwhile, therefore, to identify the management strategy which achieves the highest level of effectiveness for a given budget. Since the cost-effectiveness curves do not incorporate strategy implementation costs, again it is necessary to examine the decision in light of allowable implementation costs. For example, say the total budget cannot exceed $15 million. The highest level of effectiveness achievable for less than $15 million treatment cost is CmpMgt in conjunction with treatment by coagulation. With this strategy a relative eutrophication of 8 can be attained for a treatment cost of $10.5 million. This combination would then be selected so long as the implementation costs of CmpMgt were less than $4.5 million, the difference between the treatment cost of $10.5 million under CmpMgt and the budget constraint of $15 million. If this criterion could not be met, then a similar examination of other strategies would proceed until the highest level of effectiveness is achieved within the budget constraint.

Some control measures would not only be cost-savings because of reduced treatment requirements, but would also generate revenues which would be used to effect or carry out that treatment, just as highways are financed by a tax on gasoline.

In Section VII, the possible revenue potential of a national excise tax on phosphate detergents was examined. What such a tax might do in the Lake Erie basin is presented here as an example case. Beginning with present usage patterns of high phosphate, low phosphate, no phosphate detergents, and of soap in the basin, the question for analysis is: What will be the case if a change in use patterns is brought about by means of a tax on high phosphate detergents? To do this, four cases representing shifts from use of high phosphate detergents are analyzed to determine the tax rates necessary to induce the change, the potential revenue from the tax, and the effect on treatment cost generated from the model. Analysis is based on the following assumptions. First, some elasticity (percentage change in quantity divided by the percentage change in price) for the change caused by introducing the tax is assumed. An elasticity of 0.75 (4 percent change in price gives a 3 percent change in quantity) is selected because it seems a reasonable one. There would be no precise way of knowing before the change what the response is going to be. Second, assume that people are consuming on a per capita basis approximately 32 pounds of cleaning agents per year. See 1973 estimate in Table 38 for consumption of detergent. In the example soap adds another 10 percent to the total initially. Finally, assume the price of high phosphate detergent to be 20¢ a pound initially, the prices of other products to remain constant. With these assumptions, the kind of tax rate would be required to bring about the changes in consumption patterns postulated in Table 43 on Lake Erie and the revenues that would be generated by it are calculated.

It can be observed that Case 3 provides the greatest revenue and that while going to Case 4 may be cost-saving at some levels of treatment

Table 43. ANALYSIS OF EXCISE TAX ON HIGH PHOSPHATE DETERGENTS--LAKE ERIE EXAMPLE

	% cleaning agents that are high phosphate	per capita consumption of high phosphate	total consumption in basin,(1) kg x 10^6	tax rate,(2) cents	tax revenue,(3) \$ x 10^6
Initial Condition	.7	22.4	127	None	None
Case 1	.6	19.2	109	3.8	9.22
Case 2	.5	16	91	7.6	15.20
Case 3	.35	11.2	64	13.4	18.76
Case 4	.2	6.4	36	19.0	15.20

(1) per capita consumption X population of 12.5 million

(2) this is the rate needed to bring about the change postulated in each case given that elasticity = .75

e.g. Case 1

$$E = \frac{\% \Delta \text{ in } Q}{\% \Delta \text{ in } P}$$

$$.75 = \frac{\frac{18.2}{127}}{X\,\%} = \frac{14.3\%}{X\,\%}$$

$$X = 19.2\% \text{ and}$$

$$19.2\% \text{ of } 20¢ \text{ is } 4¢$$

(3) consumption X rate

it would, in this example, result in a loss of revenues. For instance, for a treatment level at 90 percent removal, the following cost-savings and revenues would be realized.

	Cost	Savings	Rev.	Total
Initial Condition	37.1 M	-	-	-
Case 1	23.4 M	13.7 M	9.21 M	22.9 M
Case 2	21.9 M	15.2 M	15.2 M	30.4 M
Case 3	35.2 M	1.9 M	18.8 M	20.7 M
Case 4	35.2 M	1.9 M	15.2 M	17.1 M

In this situation, Case 2 yields the greatest total cost-savings and tax revenues combined. Other removal rates would yield different results.

This has been a simple example which has precluded some very real problems and some hidden assumptions. Some of these are that all four materials have equal cleaning power per pound, that the higher price of high phosphate detergent causes a substitution and not a reduction in overall purchases of cleaning agents, and finally that people change their consumption patterns rather than their shopping location to an untaxed area. The lower the level of government levying the tax the more likely people are to avoid it by simply buying outside the taxed area.

This example, however, does illustrate that if a tax is to be used as a regulating device that our model could be used to suggest what the appropriate rate of tax should be.

Summarizing a general conclusion for Lake Erie in terms of management policy, it is clear that the lake can be brought to noneutrophic levels through comprehensive management and the use of coagulation as a relatively inexpensive treatment method. Furthermore, expensive treatment processes are not able to accomplish this without the use of some management of phosphate sources in the basin.

Lake Michigan

For the Lake Michigan case, the present phosphorus loading will apparently not cause serious problems of eutrophication. From this standpoint, therefore, treatment would be unnecessary. Nevertheless, consideration of providing a margin of safety by implementing management control on various inputs could be valuable in preserving the future quality of the lake. A decision of whether or not such a control is justified would be made following the same line of reasoning developed in the previous examples. As a general conclusion for Lake Michigan, where future costs to correct problems can be averted it makes sense to opt for better management of phosphorus sources in preference to treatment programs as the means for ensuring maintenance of the eutrophication level in the presently acceptable range.

Summary

This section has developed the basic analytical notions for application of cost-effectiveness analysis in selection of strategies for phosphate management. While the real costs of strategy implementation were discussed, the actual estimation of such costs for use in cost-effectiveness analysis could not be accomplished within the scope of this project. Certainly a useful extension of this research would be further elaboration of the cost-effectiveness analytical framework through investigation and estimation of these costs, and using them in further testing and applying the mass flow and treatment optimization models in cost-effectiveness studies for selected basins. Even so, partial cost-effectiveness curves based on the impact of various strategies plus treatment were derived and the concepts of analysis and strategy selection described. The analysis was applied to two actual cases, Lake Erie and Lake Michigan. For Lake Erie, it was seen that a combination of management controls plus treatment could bring the relative eutrophication within acceptable levels. For Lake Michigan, implementation of low cost control strategies would ensure that presently acceptable levels are maintained or improved.

REFERENCES CITED

Armentrout, W.F., Jr., and L.L. Bortner. 1971. Preliminary investigations on landfill stabilization with leachate recycle. Special Research Problem, School of Civil Engineering, Georgia Institute of Technology.

Armstrong, D.E., and G.H. Rochlich. 1971. Effects of agricultural pollution on eutrophication. In Agricultural Practices and Water Quality, Iowa State University Press, Ames.

Barnard, James L., and W. Wesley Eckenfelder, Jr. 1971. Treatment-cost relationships for industrial waste treatment. Technical Report No. 23; Environmental and Water Resources Engineering, Vanderbilt University, Nashville, Tennessee.

Bartsch, A.F. 1972. Role of phosphorus in eutrophication. EPA Report No. EPA-R3-72-001, Corvallis, Oregon.

Bernhardt, H., J. Clasen, and H. Schell. 1971. Phosphate and turbidity control by flocculation and filtration. Journal American Water Works Association 63:355-368.

Besik, F. 1971. Wastewater reclamation in a closed system. Water and Sewage Works. 213 p.

Biggar, J.W., and R.B. Corey. 1969. Agricultural drainage and eutrophication. In Eutrophication: Causes, Consequences, Correctives. Proceedings International Eutrophication Symposium, Madison, Wisconsin, National Academy of Science.

Bishop, D.F., T.P. O'Farrell, and J.B. Stamberg. 1972. Physical-chemical treatment of municipal wastewater. Journal Water Pollution Control Federation 44:361.

Black, C.A. 1968. Soil-plant relationships. Chapter 8, 2nd Edition, John Wiley and Sons, Inc.

Black, C.A. 1970. Behavior of soil and fertilizer phosphorus in relation to water pollution. In Agricultural Practices and Water Quality, Iowa State University Press, Ames, Iowa.

Born, S.M. 1972. Chippewa flowage investigations. Part 1: Summary Report. Upper Great Lakes Regional Commission. University of Wisconsin Extension. Madison, Wisconsin. 155 p. and attachments.

Brezonik, P.L., and G.F. Lee. 1968. Denitrification as a nitrogen sink in Lake Mendota, Wisconsin. E.S. and T. 2:120-125.

Brown, R.L. 1971. Removal of nitrogen from tile drainage - a summary report. EPA. WPCRS-13030 ELY5/71-6. 30 p.

Brown, R.L., R.C. Bain, and M.G. Tunzi. 1969. The effects of nitrogen removal on the algal growth potential of San Joaquin Valley agricultural tile drainage effluents. Collected papers regarding nitrates in agricultural wastewater, FWQA, Washington, D.C.

Buckman, H.O., and N.C. Brady. 1969. The nature and properties of soil. Chapter 17, 7th Edition, The Macmillan Co., New York.

Carlew, G.H. 1973. Personal communication to D. Jenkins. The Soap and Detergent Association.

Carter, D.L., J.A. Bondurant, and C.W Robbins. 1971. Water soluble NO_3-nitrogen, PO_4-phosphorus and total salt balance on a large irrigation tract. Soil Science Society of America Proceedings 35:331-335.

Chapin, J.D., and P.D. Uttormark. 1972. Atmospheric contribution of nitrogen and phosphorus. University of Wisconsin Water Resources Center Technical Report WIS-WRC 73-2.

Chen, C.W. 1970. Concepts and utilities of ecological models. Journal of the Sanitary Engineering Divison, ASCE 96:1085-1097.

Clark, C.E. 1965, Hog waste disposal by lagooning. Journal of the Sanitary Engineering Division, ASCE 91(SA6):27-41.

Cohen, J.M. 1971. Wastewater treatment. Journal Water Pollution Control Federation 43:1092.

Convery, J.J. 1970. Treatment techniques for removing phosphorus from municipal wastewaters. EPA. Water Pollution Control Research Series 17010.

Cooke, G.D., T.N. Bhargava, M.R. McComas, M.C. Wilson, and R.T. Heath. 1973. Some aspects of phosphorus dynamics of the Twin Lakes watershed. In Modeling the Eutrophication Process (E.J. Middlebrooks, Ed.). Utah State University, Logan, Utah. In press.

Cooper, C.F. 1970. Man's impact on the biosphere. Journal Soil Water Conservation 25:124-127.

Cooper, R.F. 1969. Nutrient output from managed forests. In Eutrophication: Causes, Consequences, Correctives. NAS-NRC. pp. 446-463.

Culp, R.L., and G.L. Culp. 1971. Advanced wastewater treatment. Van Nostrand Reinhold Co. 310 p.

Dale, A.C., and D.L. Day. 1967. Some aerobic decomposition properties of dairy cattle manure. Transactions of the American Society of Agricultural Engineers 10:546-548.

Department of Scientific and Industrial Research. 1964. Water Pollution Research - 1963. HMSO 73-77.

Directo, L.S., R.P. Miele, and A.N. Masse. 1972. Phosphate removal by mineral addition to secondary and tertiary systems. Presented at 27th Purdue Industrial Waste Conference, Purdue University.

DiToro, D.M., D.J. O'Connor, and R.V. Thomann. 1971. A dynamic model of the phytoplankton population in the Sacramento-San Joaquin Delta. In Nonequilibrium Systems in Natural Waters. ACS, Washington, D.C. pp. 131-180.

Dodson, R.E. 1971. Pure water from sewage. The American City.

Dornbush, J.N., and J.R. Anderson. 1964. Lagooning of livestock in South Dakota. Proceedings, 19th Industrial Waste Conference, Purdue University. pp. 317-325.

Doyle, K.F. 1971. Phosphates - an unresolved water quality problem. The Bureau of National Affairs, Inc. Environmental Reporter, Monograph No. 9, 2:1-17.

Dryden, F.D. 1970. Mineral removal by ion exchange, reverse osmosis, and electrodialysis. Proceedings, Wastewater Reclamation and Reuse Workshop, Lake Tahoe, California.

Dugan, G.L., P.H. McGauhey, and D.B. Porcella. 1971. Eutrophication of surface waters–Indian Creek Reservoir. Final Report for Grant No. 16010 DNY. 115 p.

Duthie, J.R. 1973. Personal communication. Procter and Gamble Co., Cincinnati, Ohio.

Edmundson, W.T. 1972. Nutrients and phytoplankton in Lake Washington. In Nutrients and Eutrophication (G.E. Likens, Ed.). Limnology and Oceanography, Special Symposium No. 1:172-196.

Edwards, J.B., and J.B. Robinson. 1969. Changes in composition of continuously aerated poultry manure with special reference to nitrogen. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Enderlin, H.C., and E.M. Markowitz. 1962. The classification of the soil and vegetative cover types of California watersheds according to their influence on synthetic hydrographs. In National Engineering Handbook--The Hydrology Guide (Supplement A, Section IV). Soil Conservation Service, U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D.C.

Environmental Protection Agency. 1970a. Investigation of a new phosphate removal process. Water Pollution Control Research Series 17010 DJA11/70.

Environmental Protection Agency. 1970b. Study and experiments in wastewater reclamation by reverse osmosis. Water Pollution Control Research Series 17040.

Environmental Protection Agency. 1970c. Feasibility of liquid ion extraction for extracting phosphate from wastewater. Water Pollution Control Research Series 17010 EAP10/70.

Environmental Protection Agency. 1970d. The economics of clean water. Volume III. Washington, D.C.

Environmental Protection Agency. 1971a. Algal assay procedures: bottle test. National Environmental Research Center, Corvallis, Oregon.

Environmental Protection Agency. 1971b. Process design manual for phosphorus removal. Technology Transfer.

Environmental Protection Agency. 1971c. Phosphorus removal by ferrous ion and lime. Water Pollution Control Research Series 11010 EGO.

Environmental Protection Agency. 1971d. Agricultural pollution of the Great Lakes basin. Bulletin 13020-07/71.

Environmental Protection Agency. 1971e. Management of nutrients on agricultural land for improved water quality. Water Pollution Control Research Series 13020 DPB 08/71.

Environmental Protection Agency. 1971f. Wastewater demineralization by ion exchange. Water Pollution Control Research Series 17040 EEE 12/71.

Environmental Protection Agency. 1971g. Projected wastewater treatment costs in the organic chemical industry. Water Pollution Control Research Series 12020 GND 07.

Environmental Protection Agency. 1971h. Phosphorus removal and disposal from municipal wastewater. Water Pollution Control Research Series 17010 DYB 02/71.

Environmental Protection Agency. 1972. Progress report on phosphate removal cost study. National Environmental Research Center, Cincinnati.

Eppley, R.W. 1971. Eutrophication in coastal waters: nitrogen as a controlling factor. EPA Water Pollution Control Research Series 16010 EHC 12/71. 67 p.

Eppley, R.W., J.N. Rogers, and J.J. McCarthy. 1969. Half saturation constants for uptake of nitrate and ammonium by marine phytoplankton. Limnology and Oceanography 14:912.

Evans, David R., and Jerry C. Wilson. 1972. Capital and operating costs-AWT. Journal Water Pollution Control Federation 44:1.

Fast, A.W. 1971. The effects of artificial aeration on lake ecology. EPA Report on Project No. 16010 EXE. Superintendent of Documents, Washington, D.C. 469 p.

Federal Water Pollution Control Administration. 1966. Report on pollution of the navigable water of Moriches Bay and eastern section of Great South Bay, Long Island, New York. Metuchen, New Jersey.

Federal Water Pollution Control Administration, U.S. Department of Interior. 1968. Lake Erie report. A plan for water pollution control. Great Lakes Region, Chicago, Illinois.

Federal Water Pollution Control Administration. 1969. Mathematical model of tertiary treatment by lime addition. Report No. TWRC-14, Ohio Basin Region, Cincinnati, Ohio.

Ferguson, F.A. 1968. A nonmyopic approach to the problem of excess algal growth. Environmental Science and Technology 2:188-193.

Filip, D.S., E.J. Middlebrooks, and D.B. Porcella. 1973. Chemical and biostimulatory properties of feedlot runoff. Utah State University; submitted for publication.

Fitzgerald, G.P. 1969. Field and laboratory evaluation of bioassays for nitrogen and phosphorus with algae and aquatic weeds. 14:206-212.

Fitzgerald, G.P. 1971. Algicides. Literature review No. 2, Eutrophication Information Program. The University of Wisconsin, Water Resources Center, Madison, Wisconsin. 50 p.

Forrester, J.W. 1971. Counterintuitive nature of social systems. Technology Review 75:53.

Frey, D.G. (Ed.). 1966. Limnology in North America. University of Wisconsin Press, Madison, Wisconsin. 734 p.

Fried, M., and H. Broeshart. 1967. The soil-plant system in relation to inorganic nutrition. Chapter 2, Academic Press, New York.

Frink, C.R. 1967. Nutrient budget: rational analysis of eutrophication in a Connecticut lake. E.S. and T. 1:425-428.

Fullam, H.T., and B.P. Faulkner. 1971. Inorganic fertilizer and phosphate mining industries - water pollution and control. EPA Water Pollution Control Research Series 12020 FPD, 09/71. 225 p.

Fuller, R.H. 1972. Investigation of Bear Lake, Idaho-Utah. NSF Special Student Project, Utah State University. Mimeo.

Fungaroli, A.A., and R.L. Steiner. 1971. Laboratory study of behavior of a sanitary landfill. Journal Water Pollution Control Federation 43:252.

Gerloff, G.C. 1969. Evaluating nutrient supplies for the growth of aquatic plants in natural waters. In Eutrophication: Causes, Consequences, Correctives (NAS-NRC). Publ. 1700. pp. 537-555.

Gilbertson, C.B., T.M. McCalla, J.R. Ellis, O.E. Cross, and W.R. Woods. 1971. Runoff, solid wastes, and nitrate movement on beef feedlots. Journal Water Pollution Control Federation 43:483-493.

Goldberg, M.C. 1970. Sources of nitrogen in water supplies. In Agricultural Practices and Water Quality (Ted L. Willrich and George E. Smith, Eds.). The Iowa State University Press, Ames, Iowa.

Goldman, C.R. 1965. Micronutrient limiting factors and their detection in natural phytoplankton populations. Memorie Ist. Ital. Idrobiol., Suppl. 18:121.

Goldman, C.R., and R. Armstrong. 1969. I. Productivity: primary productivity in Lake Tahoe, California. Verh. Internat. Verein. Limnol., 17:49-71.

Goldman, C.R., and R.C. Carter. 1965. An investigation by rapid Carbon-14 bioassay of factors affecting the cultural eutrophication of Lake Tahoe, California-Nevada. Journal Water Pollution Control Federation 37:1044-1059.

Goldman, J.C., D.B. Porcella, E.J. Middlebrooks, and D.F. Toerien. 1972. The effect of carbon on algal growth - its relationship to eutrophication. Water Research 6:637-679.

Grissinger, E.H., and L.L. McDowell. 1970. Sediment in relation to water quality. Water Resources Research Bulletin 6:7-14.

Hannapel, R.J., W.H. Fuller, and R.H. Fox. 1964. Phosphorus movement in a calcareous soil: II. Soil microbial activity and organic phosphorus movement. Soil Science 97:421-427.

Hanson, L.D., and W.E. Feuster. 1969. What is killing our lakes. Crops and Soils 22:13-15.

Hart, S.A. 1960. The management of livestock manure. Transactions, American Society of Agricultural Engineers 3:78-80.

Hart, S.A., and M.E. Turner. 1965. Lagoons for livestock manure. Journal of the Water Pollution Control Federation 37:1578-1596.

Harter, R.D. 1968. Adsorption of phosphorus by lake sediments. Soil Science Society of America Proceedings 32:514-518.

Hasler, A.D. 1947. Eutrophication of lakes by domestic sewage. Ecology 28:383.

Hillhouse, W.A., and J.L. DeWeerdt. 1971. Legal devices for accommodating water resources development and environmental values. NTIS Report No. PB 208 835. 763 p.

Holt, R.F., R.H. Dowdy, and D.R. Timmons. 1970a. Chemistry of sediments in water. In Agricultural Practices and Water Quality, Iowa State University Press, Ames, Iowa.

Holt, R.F., D.R. Timmons, and J.L. Latterell. 1970b. Accumulation of phosphate in water. Journal Agr. Food Chem. 18:781-784.

Horne, A.J., and C.R. Goldman. 1972. Nitrogen fixation in Clear Lake, California. I. Seasonal variation and the role of heterocysts. Limnology and Oceanography 17:678-692.

House Committee on Government Operations. 1970. Phosphates in detergents and the eutrophication of American waters. 23rd Report of the Committee. Superintendent of Documents, Washington, D.C.

House Government Operation Subcommittee on Conservation and Natural Resources. 1969. Phosphates in detergents and the eutrophication of America's waters. Washington, D.C., U.S. Government Printing Office.

Hrbacek, J. 1965. Annual report of the director. Hydrobiol. Lab., Czech. Acad. Sci. No. 6.

Humenik, F.J. 1972. Swine waste characterization and evaluation of animal waste treatment alternatives. Water Resources Research Institute, University of North Carolina, Report No. UNC-WRRI-72-61.

Hutchinson, G.E. 1957. A treatise on limnology, Volume 1, geography, physics and chemistry. John Wiley and Sons, Inc., New York. 1115 p.

Hutchinson, G.E. 1969. Eutrophication, past and present. In Eutrophication: Causes, Consequences, Correctives. National Academy of Science, Publ. 1700. pp. 17-26.

Hutchinson, G.E. 1973. Eutrophication. American Scientist 61:269-279.

Institute of Ecology, The. 1971. Man in the living environment. Report of the Workshop on Global Ecological Problems. University of Wisconsin, Institute of Ecology. 267 p.

Jeffrey, E.A., E.C. Blackman, and R.L. Ricketts. 1963. Aerobic and anaerobic digestion characteristics of livestock wastes. Engineering Series Bulletin No. 57, University of Missouri.

Jenkins, D.I. 1973. Personal communication. University of California, Berkeley.

Jenkins, David, J.F. Ferguson, and Arnold B. Menar. 1971. Review paper: chemical processes for phosphorus removal. Water Research 5:369-389.

Jenkins, D.I., A.J. Horne, W.J. Kaufman, and P.H. McGauhey. 1972. Environmental impact of detergent builders on the waters of the State of California. Report to the California State Water Resources Control Board. SERL Rept. 72-8. University of California. 61 p.

Jernelov, A. 1970. Phosphate reduction in lakes by precipitation with aluminum sulfate. Presented at the 5th International Water Pollution Research Conference, San Francisco, California.

Jitts, H.R., C.D. McAllister, K. Stephen, and J.D.H. Strickland. 1964. Journal Fisheries Research Board, Canada 21:139.

Johnston, W.R., F. Illihadich, R.M. Daum, and A.F. Pillsbury. 1965. Nitrogen and phosphorus in tile drain effluent. Soil Science Society of America Proceedings 29:287-289.

Jurinak, J.J. 1973. Personal communication. Utah State University.

Kaufman, Warren J., and Michael J. Humerick. 1970. Candidate process systems - an overview. Proceedings, Wastewater Reclamation and Reuse Workshop. Lake Tahoe, California, June 25-27, 1970.

Kearl, C.D. 1965. Economic considerations in producing corn silage in New York State. A.E. Research, Department of Ag. Economics, Cornell University, Ithaca, New York.

Keinath, Thomas M. 1972. Removal of impurities from trickling filter effluents by coagulation. Report No. 31. Water Resources Research Institute, Clemson University, Clemson, South Carolina.

Kerr, Robert S. 1971. Desalination of agricultural tile drainage. EPA Water Pollution Research Series 13030 ELY 05/71-72.

Ketchum, B.H. 1939. The absorption of phosphate and nitrate by illuminated cultures of Nitzschia closterium. Am. J. Bot. 26:399-407.

Kuentzel, L.E. 1969. Bacteria, carbon dioxide, and algal blooms. Journal Water Pollution Control Federation 41:1737-1747.

Laird, W.E., and C.R. Rinehart. 1967. Neglected aspects of industrial subsidy. Land Economics 43:25-31.

Lange W. 1971. Limiting nutrient elements in filtered Lake Erie water. Water Research 5:1031-1048.

Latterell, J.J., R.F. Holt, and D.R. Timmons. 1971. Phosphate availability in lake sediments. Journal Soil Water Conservation 26:21-24.

Laurent, P.J., J. Garacher, and P. Vivier. 1970. The condition of lakes and ponds in relation to the carrying out of treatment measures. Presented at the 5th International Water Pollution Research Conference, San Francisco, California.

Lee, G.F. 1970. Eutrophication. Occasional Paper No. 2, Eutrophication Information Program. The University of Wisconsin, Water Resources Center, Madison, Wisconsin. 39 p.

Lee, G.F. 1972. Phosphorus, water quality and eutrophication of Lake Michigan. Presented at Lake Michigan Enforcement Conference, Sept. 1972. Mimeo. 31 p.

Lewis, R.W. 1970. Phosphorus. I No. 1970 Mineral Facts and Problems. U.S. Bureau of Mines. p. 1139.

Libby, D.V., G.R. Bell, and O.A. Wissing. 1972. Chemical-physical treatment of municipal wastewater using continuous countercurrent filtration. Journal Water Pollution Control Federation 44:574.

Liebman, H. 1970. Biological and chemical investigations on the effect of sewage of the eutrophication of Bavarian lakes. Presented at the 5th International Water Pollution Research Conference, San Francisco, California.

Likens, G.E. (Ed.). 1972. Nutrients and eutrophication: The limiting nutrient controversy. Special Symposium 1. Limnol. and Oceanog. 328 p.

Likens, G.E., F.H. Bormann, N.M. Johnson, D.W. Fisher, and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40: 223-47.

Little, F.J. 1966. Agriculture and the prevention of river pollution as experimented in the west of Scotland. Journal Proceedings of the Institute of Sewage Purification. pp. 452-454.

Loehr, R.C. 1967. Effluent quality from anaerobic lagoons treating feedlot wastes. Journal of the Water Pollution Control Federation 39:384-391.

Loehr, R.C. 1969a. Animal wastes - a national problem. Journal of the Sanitary Engineering Division, American Society of Civil Engineers (SA2).189-221.

Loehr, R.C. 1969b. Treatment of wastes from cattle feedlots - field results. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Loehr, R.C. 1970. Drainage and pollution from beef cattle feedlots. Journal of the Sanitary Engineering Division, American Society of Civil Engineers 96(SA6):1295-1309.

Loehr, R.C. 1971. Alternatives for the treatment and disposal of animal wastes. Journal of the Water Pollution Control Federation 43:668-678.

Loehr, R.C. 1972. Agricultural runoff characteristics and control. Journal of the Sanitary Engineering Division, American Society of Civil Engineers 98(SA6):909-925.

Loehr, R.C., and R.W. Agnew. 1967. Cattle wastes - pollution and potential treatment. Journal of the Sanitary Engineering Division, American Society of Civil Engineers 93(SA4):72-91.

Logue, P. 1959. Utilization and economics of phoshorus and its compounds. In Phosphorus and its Compounds (by J. Van Wazer). II:987.

Mackenthun, K.M. 1965. Nitrogen and phosphorus in water. USPHS (now EPA), R.A. Taft Center, Cincinnati, Ohio.

Mackenthun, K.M., L.E. Keup, and R.K. Stewart. 1968. Nutrients and algae in Lake Sebasticook, Maine. Journal Water Pollution Control Federation, Research Supplement 40:R72.

Mackenthun, K.M., L.A. Leuschow, and C.D. McNabb. 1960. A study of the effects of diverting the effluent from sewage treatment upon the receiving stream. Wisconsin Academy of Sciences, Arts and Letters, Trans. 49:51-72.

Maloney, T.E., W.E. Miller, and T. Shiroyama. 1972. Algal response to nutrient additions in natural waters. I. Laboratory assays. In Nutrients and Eutrophication (G.E. Likens, Ed.). Limnology and Oceanography, Special Symposium No. 1:134-140.

Martin, W.P., W.E. Feuster and L.D. Hanson. 1970. Fertilizer management and pollution control. In Agricultural Practices and Water Quality, Iowa State University Press, Ames.

McCarty, P.L. 1971. Phosphorus and nitrogen removal by biological systems. In Wastewater Reclamation and Reuse Workshop, Proceedings. SERL, University of California, Berkeley. pp. 226-251.

McGauhey, P.H., G.L. Dugan, and D.B. Porcella. 1971. Eutrophication of surface waters - Lake Tahoe. Final Report for Grant No. 16010DSW 05/71. 154 p.

McGauhey, P.H., G.A. Rohlich, E.A. Pearson, E.J. Middlebrooks, D.B. Porcella, A. Aleti, and M. Tunzi. 1969. Eutrophication of surface waters - Lake Tahoe: laboratory and pilot pond studies. Lake Tahoe Area Council, South Lake Tahoe, California. 180 p.

Megard, R.O. 1971. Eutrophication and the phosphorus balance of lakes. Presented at the American Society of Agricultural Engineers, Chicago, Winter Meeting. 24 p.

Megard, R.O. 1972. Phytoplankton, photosynthesis and phosphorus in Lake Minnetonka, Minnesota. Limnology and Oceanography 17:68-87.

Merz, R.C. 1954. Investigation of leaching of a sanitary landfill. State of California Water Pollution Control Board Publication No. 10. Sacramento, California.

Meyers, D.W., E.J. Middlebrooks, and D.B. Porcella. 1972. Effects of land use on water quality: Summit Creek, Smithfield, Utah. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Middlebrooks, E.J., and D.B. Porcella. 1970. Rational multivariate algal growth kinetics. Technical Note, Journal of the Sanitary Engineering Division, American Society of Civil Engineers 97:133-140.

Middlebrooks, E.J., D.B. Porcella, E.A. Pearson, P.H. McGauhey, and G.A. Rohlich. 1971. Biostimulation and algal growth kinetics in waste water. Journal Water Pollution Control Federation 43:454-473.

Middlebrooks, E. Joe, James H. Reynolds, Gerald L. Shell, and Norman B. Jones. 1972. Modification of existing wastewater treatment plants in Utah to meet Class C water quality standards. Presented at the Joint Meeting Intermountain Section, AWWA and Utah Water Pollution Control Association, Provo, Utah, 23-24 September, 1972.

Milway, C.P. 1970. Eutrophication in large lakes and impoundments. Organization of Economic Cooperation and Development. Uppsala Symposium, Paris. 560 p.

Miner, J.R. 1967. Water pollution potential of cattle feedlot runoff. Unpublished Doctoral Thesis, Kansas State University, Manhattan, Kansas.

Miner, J.R., R.I. Lipper, L.R. Find, and J.W. Funk. 1966. Cattle feedlot runoff - its nature and variation. Journal Water Pollution Control Federation 38:1582-1591.

Minshall, N.E., S.A. Witzel, and M.S. Nichols. 1970. Stream enrichment from farm operations. Journal of the Sanitary Engineering Division, American Society of Civil Engineers 96:513-524.

Monod, J. 1949. The growth of bacterial cultures. Annual Review of Microbiology 3:371.

Moore, J.A. 1969. Managing livestock to control pollution. Bulletin 13, Water Pollution by Nutrient Sources, Effects and Control, Water Resources Research Center, University of Minnesota, Minneapolis.

Mortimer, C.H. 1969. Physical factors with bearing on eutrophication in lakes in general and in large lakes in particular. In Eutrophication: Causes, Consequences, Correctives (NAS-NRC). Publ. 1700. pp. 340-368.

National Academy of Science. 1969. Eutrophication: Causes, consequences, correctives. Proceedings of a Symposium. National Academy of Sciences, Washington, D.C. Publ. 1700. 669 p.

Nelson, L.B. 1972. Agricultural chemicals in relation to environmental quality. Journal Environmental Quality 1:2-6.

Norton, T.E., and R.W. Hansen. 1969. Cattle feedlot water quality hydrology. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

O'Brien, W.J. 1972. Limiting factors in phytoplankton algae: their meaning and measurement. Science 178:616-617.

Odum, E.P. 1959. The fundamentals of ecology. W.B. Sanders Co., Philadelphia. 546 p.

Oglesby, R.T. 1969. Effects of controlled nutrient dilution on the eutrophication of a lake. In Eutrophication: Causes, Consequences, Correctives, NAS-NRC. pp. 483-493.

Okun, D.A. 1972. Phosphates in detergents--bane or boon. Environmental Affairs II:64-89.

Olsey, R.W., R.N. Rickles, and R.B. Taylor. 1969. Relative economics of animal waste disposal by selected wet and dry techniques. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Overbeck, J. 1962a. Untersuchungen zum Phosphathaushalt von Grünalgen. II. Die Verwertung von Pyrophosphat und organisch gebundenen Phosphaten und ihre Beziehung zu den Phosphatenen von Scenedesmus quadricanda (Turp.). Brob. Arch. Hydrobiol. 58:81-108.

Overbeck, J. 1962b. Untersuchungen zum Phosphathaushalt von Grünalgen. III. Das Verhalten der Zellfraktioner von *Scenedesmus quadricanda* (Turp.). Brob. im Tageszyclus unter verscheidener Belichtungsbedingungen und bei verscheidener Phosphatverbindungen. Arch. Mikrob. 41:11-26.

Owens, M., and G. Wood. 1968. Some aspects of the eutrophication of water. Water Research 2:151-159.

Owens, T.R., and W.L. Griffin. 1968. Economics of water pollution control for cattle feedlot operations. Special Report No. 9, Department of Agricultural Economics, Texas Technological College, Lubbock, Texas.

Ozanne, P., D.J. Kirton, and T.C. Shaw. 1961. The loss of phosphorus from sandy soils. Austr. J. Agr. Res. 12:409-423.

Pennypacker, S.P. 1967. Renovation of wastewater effluent by irrigation of forest land. Journal Water Pollution Control Federation 39:285.

Poelma, H.R. 1966. The biological breakdown of pig urine. Bulletin No. 18, Institute for Farm Buildings, Wageningen, Netherlands.

Pohland, F.G. 1972. Landfill stabilization with leachate recycle. Annual Progress Report, EPA Project No. EP-00658. Georgia Institute of Technology, Atlanta, Georgia.

Porcella, D.B. 1969. Continuous-flow (chemostat) bioassays. Proceedings of the Eutrophication-Biostimulation Assessment Workshop (E.J. Middlebrooks et al., Eds.). University of California, Berkeley. pp. 7-22.

Porcella, D.B., P.A. Cowan, and E.J. Middlebrooks. 1973. Detergent and non-detergent phosphorus in sewage. Report submitted for publication. 20 p.

Porcella, D.B., P. Grau, C.H. Huang, J. Radimsky, D.F. Toerien, and E.A. Pearson. 1970. Provisional algal assay procedures. First Annual Report. SERL Report No. 70-8. University of California, Berkeley. 180 p.

Porcella, D.B., J.S. Kumagai, and E.J. Middlebrooks. 1970. Biological effects on sediment-water nutrient interchange. Proceedings ASCE 96(SA4):911-926.

Porcella, D.B., P.H. McGauhey, and G.L. Dugan. 1972a. Response to tertiary effluent in Indian Creek Reservoir. Journal WPCF 44: 2148-2161.

Porcella, D.B., K.L. Schmalz, and W.A. Luce. 1972b. Sediment-water nutrient interchange in eutrophic lakes. Seminar on Eutrophication and Biostimulation, California Department of Water Resources, Sacramento, California. pp. 83-109.

Provisional Algal Assay Procedures. 1969. Joint Industry-Government Task Force on Eutrophication, P.O. Box 3011, Grand Central Station, New York. 62 p.

Prowse, G. 1969. The role of cultural pond fish in the control of eutrophication in lakes and ponds. Verh. Intl. Ver. Limnol. 17:594.

Rawson, D.S. 1960. A limnological comparison of twelve large lakes in northern Saskatchewan. Limnology and Oceanography 5:195-211.

Rebhun, M., and W.J. Kaufman. Removal of organic contaminants - sorption of organics by synthetic resins and activated carbon. Sanitary Engineering Research Laboratory, University of California, Berkeley. SERL Report No. 67-9.

Reynolds, J.R., E.J. Middlebrooks, and D.B. Porcella. 1973. Interactions of temperature, limiting nitrogen, and phenol in semicontinuous culture. Paper to be presented at Purdue Industrial Waste Conference.

Rohlich, G.A., and P.D. Uttormark. 1972. Wastewater treatment and eutrophication. In Nutrients and Eutrophication (G.E. Likens, Ed.). Limnology and Oceanography Special Symposium No. 1. pp. 231-245.

Rosenberry, P.E., and W.C. Moldenhaven. 1971. Economic implications of soil conservation. Journal Soil Water Conservation 26:221-224.

Ross, J.L. 1970. Advanced waste treatment in Nassau County, New York. Water and Wastes Engineering 7(2):38-39.

Russell, E.W. 1961. Soil conditions and plant growth. Chapter 26, 9th Edition, John Wiley and Sons, N.Y.

Ryther, J.H., and W.M. Dunston. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science 171:1008-1013.

Sawyer, C.N. 1947. Fertilization of lakes by agricultural and urban drainage. Journal New England Water Works Association 61:109.

Sawyyer, Clair N. 1960. Chemistry for sanitary engineers. McGraw-Hill. 367 p.

Scalf, M.R., F.M. Pfeffer, L.D. Lively, J.L. Witherow, and C.P. Priesing. 1969. Phosphate removal at Baltimore, Maryland. Journal Sanitary Engineering Division, American Society of Civil Engineers 95:817-827.

Schelske, C.L., and E.F. Stoermer. 1972. Phosphorus, silica and eutrophication of Lake Michigan. In Nutrients and Eutrophication (G.E. Likens, Ed.). Limnology and Oceanography Special Symposium No. 1. pp. 157-171.

Schindler, D.W. 1971. Nutrients and eutrophication. Journal of Phycology 7:321-329.

Schindler, D.W. 1972. Personal communication.

Schindler, D.W., F.A.J. Armstrong, S.K. Holmgren, and G.J. Brunskill. 1971. Eutrophication of Lake 227, Experimental Lakes Area, Northwestern Ontario, by addition of phosphate and nitrate. Journal Fisheries Research Board, Canada 28:1763-1782.

Schmid, L.A., and R.I. Lipper. 1969. Swine wastes, characterization and anaerobic digestion. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Shannon, E.E., and P.L. Brezonik. 1972. Relationships between lake trophic state and nitrogen and phosphorus loading rates. E.S. and T. 6:719-725.

Shoup, C.S. 1969. Public finance. Aldine Publishing Co., Chicago. 660 p.

Silvey, W.G. 1970. Clear Lake Interagency Advisory Committee Meeting. Oral Presentation of US Geological Survey Study.

Singer, Philip C. 1972. Anaerobic control of phosphate by ferrous ion. Journal Water Pollution Control Federation 44(4):663.

Smith, R. 1968. Cost of conventional and advanced treatment of wastewater. Journal Water Pollution Control Federation 40:1546.

Smith, R., and W.F. McMichael. 1969. Cost and performance estimates for tertiary wastewater treating processes. Robert A. Taft Water Research Center. Report No. TWRC-9.

Sonzogni, W.C., and G.F. Lee. 1971. Effect of diversion of domestic waste waters on phosphorus content and eutrophication of the Madison Lakes. Presented at the 73rd National Meeting American Institute of Chemical Engineering, Minneapolis, August 1972. Mimeo. 30 p.

Spiegel, Milton, and T.H. Forrest. 1969. Phosphate removal: summary of papers. Journal Sanitary Engineering Division, American Society of Civil Engineers.

Spencer, W.F. 1957. Distribution and availability of phosphate added to lakeland fine sand. Soil Science Society of America Proceedings 21:141-144.

Srinath, E.G., and S.C. Pillai. 1972. Phosphorus in wastewater effluents and algal growth. Journal Water Pollution Control Federation 44:303.

Stewart, K.M., and G.A. Rohlich. 1967. Eutrophication - a review. A report to the California Water Quality Control Board. Publ. No. 34:188.

Struzeski, E. 1971. Environmental impact of deicing. Environmental Protection Agency WPCRS 11040 GKK, 06/71. Superintendent of Documents, Washington, D.C. 120 p.

Stumm, W., and J.O. Leckie. 1970. Phosphate exchange with sediments: its role in the productivity of surface waters. Presented at 5th Intern. Wat. Poll. Res. Conf. July, 1970, San Francisco, California.

Stumm, W., and J.J. Morgan. 1970. Aquatic chemistry. Chapter 10, Wiley-Interscience, N.Y.

Stumm, W., and E. Stumm-Zollinger. 1971. Chemostasis and homeostasis in aquatic ecosystems: principles of water pollution. In Adv. in Chem., No. 106, Am. Chem. Soc., Washington, D.C.

Sylvester, R.O. 1961. Nutrient content of drainage water from forested urban and agricultural areas. In Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TRW61-3:80-87.

Sylvester, Robert O., and Robert W. Seabloom. 1963. Quality and significance of irrigation return flow. J. Irrig. and Drain. Div., ASCE 89(IR3):1-27.

Taiganides, E.P. 1964. Disposal of animal manures. Proceedings, 19th Industrial Waste Conference, Purdue University.

Taiganides, E.P., and T.E. Hazen. 1966. Properties of farm animal excreta. Transactions, American Society of Agricultural Engineers 9:374-376.

Taiganides, E.P., T.E. Hazen, E.R. Baumann, and D. Johnson. 1964. Properties and pumping characteristics of hog wastes. Transactions, American Society of Agricultural Engineers 7:123.

Task Group 2610 P. 1967. Sources of nitrogen and phosphorus in water supplies. J. Am. Water Works Assoc. 59:344-366.

Taylor, A.W. 1967. Phosphorus and water pollution. J. Soil Water Cons. 22:228-231.

Thomas, E.A. 1972. Phosphate removal by recircling ion sludge. Journal Water Pollution Control Federation 44:177.

Thomas, W.H. 1966. J. Phycol. 2:17.

Thompson, L.M., C.A. Black, and J.A. Zoellner. 1954. Occurrence and mineralization of organic phosphorus in soils with particular reference to associations with nitrogen, carbon and pH. Soil Sci. 77:185-196.

Tilstra, J.R., K.W. Malueg, and W.C. Larson. 1972. Removal of phosphorus and nitrogen from wastewater effluents by induced soil percolation. Journal Water Pollution Control Federation 44:796-805.

Timmons, D.R., R.E. Burwell, and R.F. Holt. 1968. Loss of crop nutrients through runoff. Minnesota Science 24:1.

Tinbergen, J. 1952. On the theory of economic policy. North Holland Publishing Co., Amsterdam.

Toerien, D.F., C.H. Huang, J. Radimsky, E.A. Pearson, and J. Scherfig. 1971. Final report: provisional algal assay procedures. SERL Report No. 71-6. University of California, Berkeley. 211 p.

Townshend, A.R., S.A. Black, and J.F. Janse. 1970. Beef feedlot operations in Ontario. Journal of the Water Pollution Control Federation 42: 195-208.

Townshend, A.R., K.A. Reichart, and J.H. Nodwell. 1969. Status report on water pollution control facilities for farm animal wastes in the province of Ontario. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Tyler, P.M., and W.H. Waggaman. 1954. Phosphatic slime: a potential mineral asset. Ind. and Eng. Chem. 46:1049-1056.

U.S. Congress. 1960. Subsidy and subsidylike programs of the U.S. Government. 86th Congress, 2nd Session, Joint Economic Committee. p. 9.

U.S. Department of Commerce. 1968. Survey of manufacturers.

U.S. Department of Commerce. 1972. Statistical abstract of the United States. Superintendent of Documents. 1017 p.

U.S. Department of Interior. 1968. Water Quality Criteria. Superintendent of Documents, Washington, D.C. 20402. 234 p.

U.S. Department of Treasury. 1968. Internal Rev. Cum. Bull. 1969/3 July Dec. p. 624.

Utah State University. 1969. Characteristics and pollution problems of irrigation return flow. Papers by Utah State University Foundation for the U.S. Department of the Interior, Federal Water Pollution Control Administration, Robert S. Kerr Water Research Center, Ada, Oklahoma.

Uttormark, P. 1973. Personal communication. University of Wisconsin, Madison.

Van Wazer, J. 1958. Phosphorus and its compounds. Vol. II.

Verduin, J. 1967. Eutrophication and agriculture in the United States. In Agriculture and the Quality of our Environment, American Association for the Advancement of Science, AAAS Publication 85:163-172.

Viets, F.G. 1970. Soil use and water quality - a look into the future. J. Agr. Food Chem. 18:789-792.

Viets, F.G. 1971. A primer on agricultural pollution: fertilizer. J. Soil Water Conservation 26:51-53.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. A Report to the Organization of Economic Cooperation and Development. Paris. DAS/CSI/68. 27:1-182.

Wadleigh, C.H., and C.S. Britt. 1969. Conserving resources and maintaining a quality environment. J. Soil Water Cons. 24:172-175.

Water Resources Council. 1968. The nation's water resources. Parts 1-7. Washington, D.C.

Webber, L.R., and D.E. Elrick. 1967. The soil and lake eutrophication. Proc. Tenth Conf. Great Lakes Res. pp. 404-412.

Weber, Walter J., Jr., C.B. Hopkins, and Ralph Bloom, Jr. 1970. Physiochemical treatment of wastewater. Journal Water Pollution Control Federation 42:83.

Weibel, S.R. 1969. Urban drainage as a factor in eutrophication. In Eutrophication: Causes, Consequences, Correctives. NAS-NRC. pp. 383-403.

Weibel, S.R., R.B. Weidner, J.M. Cohen, and A.G. Christianson. 1966. Pesticides and other contaminants in rainfall and runoff. J. American Water Works Assoc. 58:1075-1084.

Weidner, R.B., A.G. Christianson, and S.R. Weibel. 1969. Rural runoff as a factor in stream pollution. Journal Water Pollution Control Federation 41:377-384.

Wells, D.M., W. Grub, R.C. Albin, G.F. Meenaghan, and E. Coleman. 1970. Control of water pollution from Southwestern cattle feedlots. Presented at the 5th International Water Pollution Research Conference, San Francisco.

Willrich, T.L. 1966. Primary treatment of swine waste by lagooning. Proceedings of the National Symposium on Animal Waste Management, American Society of Agricultural Engineers, Publication No. SP-0366.

Wischmeier, W.H. 1971. The erosion equation--a tool for conservation planning. Proceedings Soil Science Society of America. pp. 73-78.

Wischmeier, W.H., and D.D. Smith. 1965. Predicting rainfall - erosion losses from cropland east of the Rocky Mountains. Agr. Handbook 282. U.S. Depart. Agr., Washington, D.C.

Witzel, S.A., E. McCoy, L.B. Polowski, O.J. Attoe, and M.S. Nichols. 1966. Physical, chemical and bacteriological porperties of farm wastes (bovine animals). Proceedings, National Symposium on Animal Waste Management, American Society of Agricultural Engineers, Publication No. SP-0366. pp. 10-14.

Yee, William C. 1966. Selected removal of mixed phosphates by activated alumina. Journal American Water Works Association 59:239. February.

Young, J.L., and R.A. Crossman. 1970. Eutrophication control by plant harvesting. Journal Water Pollution Control Federation 42:R173-R183.

Zenz, David R., and Joseph R. Pivnicka. 1969. Effective phosphorus removal by the addition of alum to the activated sludge process. Proceedings 24th Purdue Industrial Waste Conference. pp. 273-300.

Zicher, E.L., K.C. Berger, and A.D. Hasler. 1956. Phosphorus release from bog lake muds. Limnology and Oceanography 1:296-303.

Zwerman, P.J., T. Greweling, S.D. Klausner, and D.J. Lathwell. 1972. Nitrogen and phosphorus content of water from tile drains at two levels of management and fertilization. Soil Science Society of America Proceedings 36:134-137.

BIBLIOGRAPHY

Atkinson, H.J., G.R. Giles, and J.G. Desjardins. 1954. Trace element content of farmyard manure. Canadian Journal of Agricultural Science 34:76-80.

Baines, S. 1964. Some aspects of the disposal and utilization of farm wastes. Journal Proceedings of the Institute of Sewage Purification. ppp. 578-588.

Bartsch, A.F. 1961. Induced eutrophication - a growing water resource problem. In Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TRW 61-3.

Bator, F.M. 1957. The simple analytics of welfare maximization. American Economic Review 47:22-59.

Baumol, W.J. 1952. Welfare Economics and the Theo y of the State. Harvard University Press, Cambridge, Mass.

Benne, E.J., C.R. Hogland, E.D. Longnecker, and R.L. Crook. 1961. Animal manures - what are they worth today. Bulletin No. 231, Agricultural Experiment Station, Michigan State University.

Bower, Blair T. 1966. Methodology for approaching water quality problems. Report No. 15. Conference Proceedings, Western Agricultural Economics Research Council, Committee on the Economics of Water Resources Development. December 7-9, 1966, Las Vegas, Nevada. pp. 67-88. Discussion by Herbert H. Stoevener. pp. 89-90.

Buchanan, J.M. 1968. A behavioral theory of pollution. Western Economic Journal. pp. 347-358.

Buchaanan, J. and W.C. Stubblebine. 1962. Externality. Economica 29:371-384.

California State Department of Water Resources. (Unpublished data). Taken from Report to California State Water Resources Control Board by the University of California, SERL Report No. 72-8.

Campbell, R.S., and J.R. Whitley. 1970. Effects of agricultural pollutants on recreational uses of surface waters. In Agricultural Practices and Water Quality (Ted L. Willrich and George E. Smith, Eds.), The Iowa State University Press, Ames, Iowa.

Casler, G.L. 1969. Economic evaluation of liquid manure systems for free stall dairy farms. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Castle, E.N. 1966. Economics of water pollution control. Water Pollution Control Federation Journal 38:789-793.

Coase, R.H. 1960. The problem of social cost. Journal of Law and Economics 3:1-44.

Cross, F.B., and M. Braasch. 1969. Quality changes in the fish-fauna of the Upper Neosho River System, 1952-1967. Transactions, Kansas Academy of Science 71:350-360.

Davis, O.A. 1963. Economic elements in municipal zoning decision. Land Economics, Vol. 39.

Dorfman, R., aand H.D. Jacoby. 1960. A model of public decisions illustrated by a water pollution policy problem. In Public Expenditures and Policy Analysis (Haveman and Margolis, Eds.). Markham Publishing Company, Chicago. pp. 173-231.

Dougal, M.D., E.R. Baumann, and J.F. Timmons. 1970. Physical and economic factors associated with the establishment of stream water quality standards. ISWRRI-27 (A-001-IA) Vol. I, 343 p., Vol. II, 644 p. (Iowa State Water Resources Research Institute).

Duffer, W.R., R.D. Kries, and C.C. Harlin, Jr. 1971. Effects of feedlot runoff on water quality of impoundments. Environmental Protection Agency, Project No. /6080 GGP.

Ecker-Racz. 1970. The politics and economics of state-local finance. Prentice-Hall.

Eckstein, O. 1958. Water resources development: the economics of project evaluation. Harvard University Press, Cambridge, Mass.

El-Sabban, F.F., T.A. Long, R.F. Gentry, and D.E.H. Frear. 1969. The influence of various factors on poultry litter composition. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Engelbrecht, R.S., and J.J. Morgan. 1961. Land drainage as a source of phosphorus in Illinois surface waters. In Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TRW 61-3:74-79.

Environmental Protection Agency. 1971. Advanced waste treatment research facility, Pomona California. Sanitation Districts of Los Angeles County.

Environmental Protection Agency. 1971. Projected wastewater treatment costs in the organic chemical industry. Water Pollution Control Research Series 12020 GND 07/71.

Ewald, W.R. 1968. Environment and policy. Indiana University Press.

Federal Water Pollution Control Administration. 1968. Water quality criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior.

Fox, I.K. 1961. Pollution: the problem of evaluation. Proceedings of the National Conference on Water Pollution, Washington, D.C., December 12-14, 1960. U.S. Department of Health, Education, and Welfare, Public Health Service, Washington, D.C. pp. 114-119.

Frankel, R.J. 1965. Water quality management: engineering-economic factors in municipal waste disposal. Water Resources Research 1:173-186.

Geldreich, E.E., R.H. Bordner, C.B. Hoff, H.F. Clark, and P.W. Kabler. 1962. Type distribution of coliform bacteria in the faeces of warm-blooded animals. Journal of the Water Pollution Control Federation 34:76-80.

Grub, W., R.C. Albin, D.M. Wells, and R.Z. Wheaton. 1969. The effect of feed, design, and management on the control of pollution from beef cattle feedlots. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Hammond, R.J. 1960. Benefit-cost analysis and water pollution control. Miscellaneous publication No. 13. Food Research Institute, Stanford University, Stanford, California.

Hart, S.A. 1963. Digestion tests of livestock wastes. Journal of the Water Pollution Control Federation 35:748-757.

Haveman, R.H. 1965. Water resource investment and the public interest. Vanberbilt University Press, Nashville.

Haveman, R.H., and J.V. Krutilla. 1969. Unemployment, idle capacity, and the evaluation of public expenditures. Johns Hopkins Press, Baltimore.

Hirsch, Werner Z. 1970. The economics of state and local government. McGraw-Hill.

Hirshleifer, J., J.C. DeHaven, and J.W. Milliman. 1960. Water supply, economics, technology, and policy. A Rand Corporation Research Study. University of Chicago Press, Chicago.

Hoover, S.R., and L.B. Jasewicz. 1967. Agricultural processing wastes: magnitude of the problem. In Agriculture and the Quality of our Environment. American Association for the Advancement of Science, AAAS Publication 85:187-203.

Irgens, R.L., and D.L. Day. 1966. Laboratory studies of aerobic stabilization of swine wastes. Journal of Agriccultural Engineering Research. p. 11.

Ives, K.J. (Chairman). 1973. Phosphorus in fresh water and the marine environment. Water Research 7:1-342.

Jones, D.D. B.A. Jones, and D.L. Day. 1968. Aerobic digestion of cattle wastes. Illinois Research 10:16-18.

Kalter, R.J. 1970. Federal evaluation of resource investments: a case study. Agr. Econ. Res. Bull. No. 313. Cornell University Water Resour. Center and Dept. of Agr. Econ., Ithaca, New York.

Kearl, C.D., and D.P. Snyder. 1968. Field crops costs and returns from farm cost accounts. A.E. Research, Department of Ag. Economics, Cornell University, Ithaca, New York.

Kneese, Allen V. 1964. The economics of regional water quality management. Johns Hopkins.

Koelliker, J.K. 1969. Soil percolation as a renovation means for livestock lagoon effluent. Unpublished Master's Thesis, Iowa State University, Ames.

Krutilla, J.V., and O. Eckstein. 1958. Multiple purpose river development. Johns Hopkins Press, Baltimore.

Likens, G.E. 1972. Nutrients and eutrophication. Limnology and Oceanography Special Symposium No. 1.

Linton, R.E. 1969. The economics of poultry manure disposal. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

Loehr, R.C. 1968. Pollution implications of animal wastes - a forward oriented review. U.S. Department of the Interior, Federal Water Pollution Control Administration, Robert S. Kern Water Research Center, Ada, Oklahoma.

Long, Norton E. 1966. New tasks for all levels of government. In Environmental Quality (Henry Jarrett, Ed.), Johns Hopkins. pp. 141-163.

McCalla, T.M., L.R. Frederick, aand G.L. Palmer. 1970. Manure decomposition and fate of breakdown products in soil. In Agricultural Practices and Water Quality, (Ted L. Willrich and George E. Smith, Eds.), The Iowa State University Press, Ames, Iowa.

McEachron, L.W., P.J. Ziverman, C.D. Kearl, and R.B. Musgrave. 1969. Economic return from various land disposal systems for dairy cattle manure. In Animal Waste Management, Cornell University Conference on Agricultural Waste Management, Syracuse, New York.

McGuiness, J.L., L.L. Harrold, and F.R. Drieibellia. 1960. Some effects of land use and treatment on small single crop watersheds. Journal Soil Water Conservation 15:65-69.

McKean, R.N. 1958. Efficiency in government through systems analysis. Publications in Operations Research, No. 3, Operations Research Society of America. A Rand Corporation Research Study. John Wiley & Sons, Inc.

McKean, R.N. 1968. Public spending. McGraw-Hill.

Mackenthun, K.M. 1968. The phosphorus problem. Journal of the American Water Works Association 60:1047-1054.

Marglin, S.A. 1968. Public investment criteria: benefit-cost analysis for planned economic growth. MIT Press, Cambridge, Mass.

Margolis, Julius. 1957. Secondary benefits, external economies, and the justification of public investment. Review of Economics and Statistics 39:228-291.

Miner, J.R., and T.L. Willrich. 1970. Livestock operations and fieldspread manure as sources of pollutants. In Agricultural Practices and Water Quality (Ted L. Willrich and George E. Smith, Eds.), The Iowa State University Press, Ames, Iowa.

Morris, W.H.M. 1966. Economics of liquid manure disposal from confined livestock. Proceedings National Symposium on Animal Waste Management, American Society of Agricultural Engineers, Publications No. SP-0366: 126-131.

Moyle, J.B. 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. Journal of Wildlife Management 20::303-320.

Niles, C.F. 1967. Egglaying house wastes. Proceedings, 22nd Industrial Waste Conference, Purdue University. p. 334.

Oates, Wallace E. 1972. Fiscal federalism. Harcourt, Brace, Jovanovich, Inc.

Panagiotis, H., J. DeBoeck, L. Stanton, and C.D. Kearl. 1960. Relation of yield and cost. A.E. Research, Department of Ag. Economics, Cornell University, Ithaca, New York.

Prest, A.R., and R. Turvey. 1965. Cost-benefit analysis: a survey. Economic Journal. pp. 683-735.

Ray, A.D. 1965. Pollution from industrial wastes and sewage. In Water Forum, Special Report 55, College of Agriculture, University of Missouri, Columbia. pp. 31-36.

Sawyer, C.N., J.B. Lackey, and R.T. Lenz. 1945. An investigation of the odor nuisances occurring in the Madison Lakes, particularly Monona, Waubesca and Kegonso from July 1942 to July 1944. Report of the Governor's Committee, Madison, Wisconsin.

Scheltinga, J.M.J. 1966. Aerobic purification of farm waste. Journal Proceedings of the Institute of Sewage Purification. pp. 585-588.

Scheltinga, J.M.J. 1966. Biological treatment of animal wastes. Proceedings of the National Symposium on Animal Waste Management, American Society of Agricultural Engineers, Publication No. SP-0366.

Singer, Neil M. 1972. Public microeconomics. Little, Brown, and Company.

Smith, S.M., and J.R. Miner. 1964. Stream pollution from feedlot runoff. Transactions, 14th Annual Conference on Sanitary Engineering, University of Kansas. pp. 18-25.

Snyder, D.P. 1968. Economic considerations of high moisture corn for dairymen. A.E. Research, Department of A. Economics, Cornell University, Ithaca, New York.

Steiner, P.O. 1959. Choosing among alternative public investments in the water resource field. American Economic Review 49:893-916.

Stewart, B.A., F.G. Viets, G.L. Hutchinson, and W.D. Kemper. 1967. Nitrate and other water pollutants under fields and feedlots. Environmental Science and Technology 1:736-739.

Tilstra, John R., Kenneth W. Malueg, and Winston C. Larson. Removal of phosphorus and nitrogen from wastewater effluent by induced soil percolation.

U.S. Bureau of the Budget. 1952. Circular A-47. (Mimeo). Washington, D.C.

U.S. Congress, Senate. 1962. Policies, standards and procedures in the formulation, evaluation, and review of plans for use and development of water and related land resources. Senate Document No. 97, 87th Congress. Government Printing Office, Washington, D.C.

U.S. Interagency Committee on Water Resources. 1958. Proposed practices for economic analysis of river basin projects. The 'The Green Book'. Washington, D.C. May 1950. (Revised May 1958.)

University of California. 1970. Wastewater reclamation and reuse workshop. Proceedings. Lake Tahoe, California, SERL, University of California, Berkeley. June 25-27.

Verduin, J. 1970. Significance of phosphorus in water supplies. In Agricultural Practices and Water Quality (Ted L. Willrich and George E. Smith, Eds.), The Iowa State University Press, Ames, Iowa.

Waksman, S.A. 1938. Humus. 2nd Edition, Williams and Wilkins, Baltimore.

Wurhman, K. 1962. Nitrogen removal in sewage treatment processes. The 15th International Congress of Limnology, Madison, Wisconsin.

APPENDIX A

FURTHER RELATIONS BETWEEN EUTROPHICATION LEVELS AND STANDING CROP ESTIMATES OF ALGAE

EUTROPHICATION PARAMETERS AND PHOSPHORUS LOADING

The relationships between phosphorus loading and phosphorus concentration in the water (Figure 8) can be expressed as:

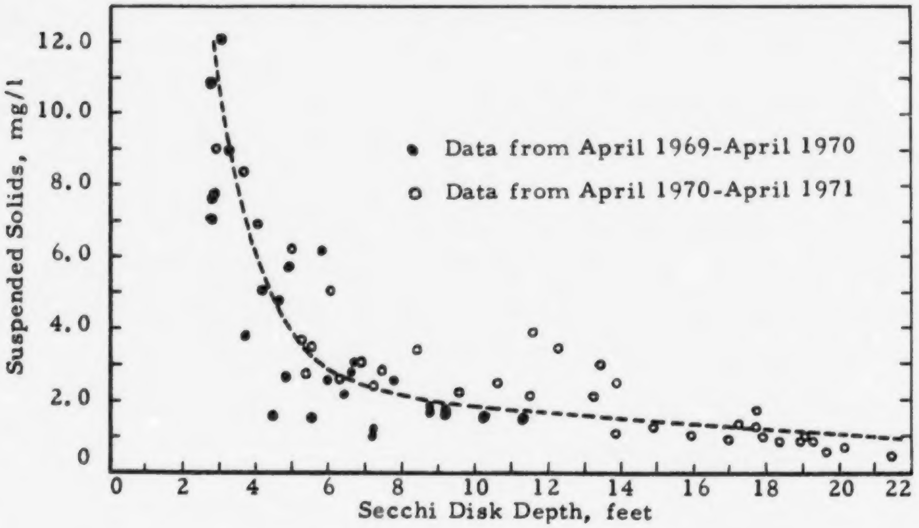
$$\text{P conc, } \mu g/l = 80 \text{ (P loading rate), } g/m^2 \text{ yr} \qquad (41)$$

Averaging the results of Edmundson (1972) and Megard (1972) for chlorophyll a versus phosphorus concentration (Figure 10), a relationship between total phosphorus concentration and an index of algal productivity can be obtained:

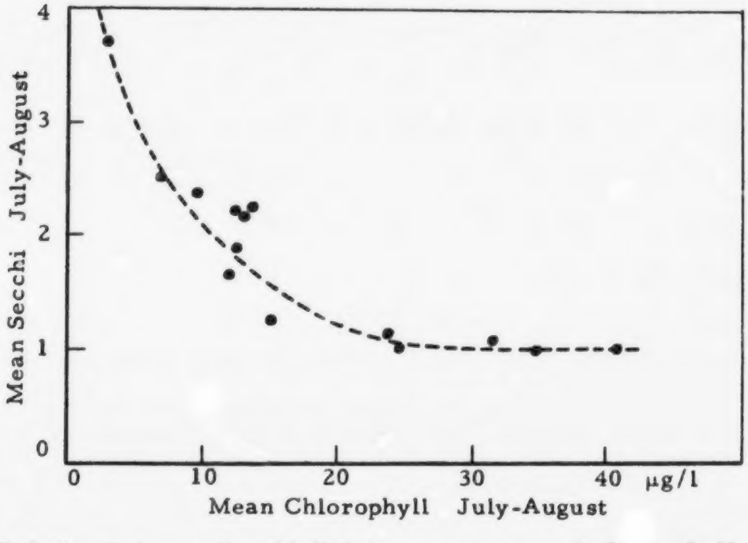
$$\text{Chlorophyll } \underline{a}, \ \mu g/l = 0.8 \text{ (Total P conc, } \mu g/l) \qquad (42)$$

Further, an inverse relationship between water clarity and chlorophyll a can be estimated (see Figure A-1 B; $r = 0.89$, calculated from Edmundson, 1972):

$$\frac{1}{\text{Secchi depth, meters}} = 0.02 \text{ (chlorophyll } \underline{a}, \ \mu g/l) + 0.3 \qquad (43)$$



A. Clarity of water (Secchi disk) as a function of suspended solids (Dugan et al, 1971)



B. Relation between Secchi disk transparency and chlorophyll. Means for July and August, chlorophyll for top 10 m, 1950, 1956/1959, 1962/1970 (Edmundson, 1972).

Figure A-1. Secchi disk is related to other parameters of algal blooms

A similar relationship between suspended material composed mostly (> 50 percent) of organic matter has been obtained (Figure A-1 A; Dugan et al., 1971):

$$\frac{1}{\text{Secchi depth, meters}} = 0.01 \text{ (suspended solids, mg/l)} + 0.1 \qquad (44)$$

For a given lake these equations allow estimates to be made of the various parameters of algal blooms (chlorophyll a, total springtime phosphorus, Secchi depth) from the annual phosphorus loading rate.

PARAMETERS OF PRODUCTIVITY

Lastly, an estimate of chlorophyll a concentrations in terms of phosphorus loading would allow an extremely crude definition of admissible and dangerous levels of eutrophication in terms of chlorophyll a and Secchi depth. Because suspended solids does not differentiate between organic and inorganic materials, it is not included here; however, Secchi depth will be included because of its more frequent use in lake studies, but with the strict warning that it also does not differentiate between organic and inorganic materials. The relationships can be determined by substituting in turn 1) the relationship between spring phosphorus concentrations and annual phosphorus loading rates (Vollenweider, 1968; see Figure 8 and Equation 41); 2) the relationship between chlorophyll a and the winter-spring phosphorus concentration (Edmundson, 1972; Megard, 1972; see Figure 10 and Equation 42); and 3) the relationships above for Secchi depth and chlorophyll a (Equation 43). Thus a provisional assumption is made that Vollenweider's spring phosphorus concentration is the same as the winter-spring concentrations described by Edmundson and Megard.

$$\text{Spring P conc, } \mu g/l = 80 \ (\text{Annual P loading rate, } g/m^2 \text{ yr})$$

$$\text{Chlorophyll } \underline{a}, \ \mu g/l = 64 \ (\text{Annual P loading rate, } g/m^2 \text{ yr})$$

$$\frac{1}{\text{Secchi depth, m}} = 1.28 \ (\text{Annual P loading rate, } g/m^2 \text{ yr}) \qquad (45)$$

As shown in Figure A-2, the relation between phosphorus loading rates and chlorophyll a and Secchi depth allows definition of levels corresponding to admissible and dangerous levels of eutrophication. These values would only be of relative value to indicate in quantitative terms a crude definition of algal population levels corresponding to a eutrophic lake; as such they should be compared to other lake systems varying in their degree of eutrophy.

Relative Eutrophication	Biomass Parameter	
	Chlorophyll a, µg/l	Secchi Depth, m
Permissible	26	1.02
Dangerous	52	0.85

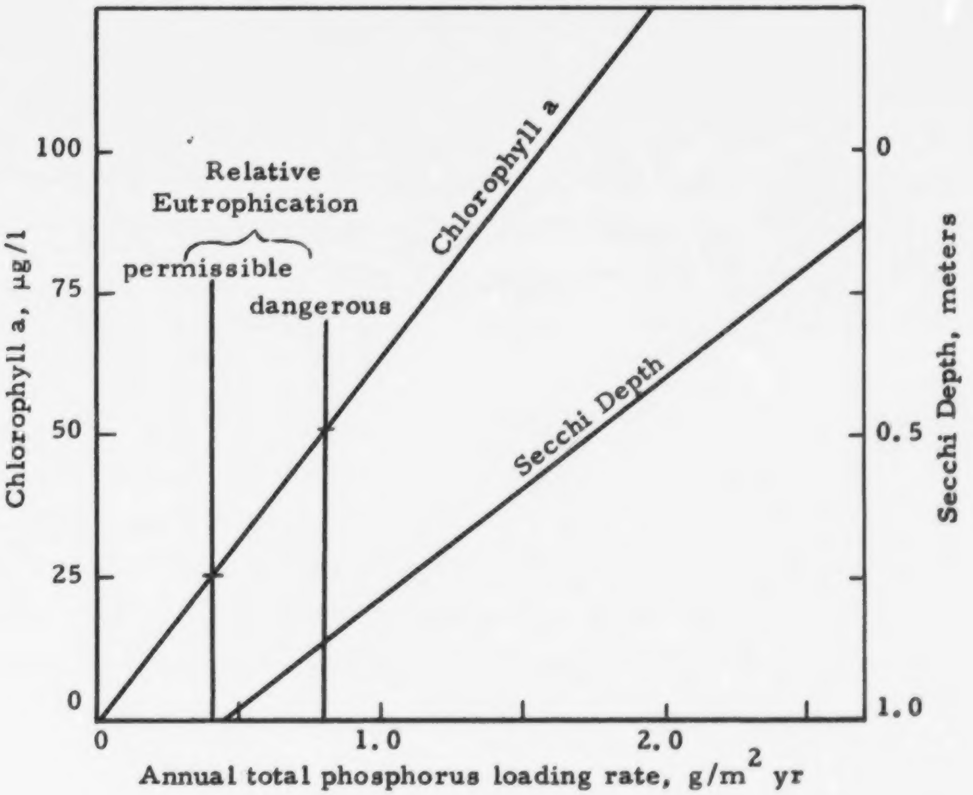


Figure A-2. An example of how a biomass (algal bloom) parameter can be related to phosphorus loading rate. Assumed mean depth of lake is 100 meters.

APPENDIX B

LANDFILLS AS A SOURCE OF PHOSPHORUS

The prediction of the quantity of phosphorus contributed to surface waters from sanitary landfill is not simple because it depends upon the condition of the landfill (saturated or not saturated) and upon whether the leachate from the fill enters surface or ground waters.

That there is some phosphorus contributed to groundwaters beneath, within, and downstream from, sanitary landfills has been demonstrated as early as 1954 (Merz, 1954). By drilling wells upstream in the groundwater aquifer running below the Riverside, California, landfill, it was demonstrated that phosphorus concentrations were higher in the water beneath and downstream from the landfill. An abbreviated list of this data is presented in Table B-1. (All data in this discussion were presented as phosphate and have been converted to phosphorus.)

While these data show that sanitary landfills do contribute phosphorus to groundwaters through leaching, such field studies are difficult to draw conclusions from in terms of phosphorus loadings from a unit (such as a metric ton or a hectare-meter) of sanitary landfill. For such data one must invariably turn to laboratory or lysimeter studies on the production of leachate from (typically) saturated "synthetic" sanitary landfills.

Table B-1. EFFECT OF LANDFILL LEACHATE ON PHOSPHORUS CONTENT OF UNDERLYING GROUNDWATER

	Inorganic phosphorus mg/l	
Location of Well	1952-1953	1953-1954
Upstream of landfill in aquifer	0.02	0.02
At head of landfill in aquifer	0.015	0.02
Immediately below landfill in aquifer	0.055	0.022
Below landfill 4 ft into aquifer	0.036	0.085
Below landfill 6 ft into aquifer	0.013	0.015
Below landfill 10 ft into aquifer	0.006	0.026
Below landfill 6 ft into aquifer	0.026	0.036
Below landfill into aquifer (depth unspecified)	0.075	0.15
Below landfill into aquifer (depth unspecified)	0.015	0.022
Below landfill 6 ft into aquifer	0.05	0.08
Below landfill into aquifer (depth unspecified)	0.28	1.04
Below landfill into aquifer (depth unspecified)	0.14	0.16
At end of landfill 4 ft into aquifer	0.22	--
At end of landfill into aquifer (depth unspecified)	0.4	0.3

Merz conducted such lysimeter studies in which parallel lysimeters were used. One lysimeter was saturated and then water applied at the rate of 76 l/week (equivalent to 2.5 cm/week). Leachate was collected and analyzed. Merz's data for total phosphorus are replotted in Figure B-1. From an estimation of the area under the curve it was determined that 5300 l of water applied to 9 m^3 of uncompacted refuse produced 70 mg total phosphorus. Assuming a density of 120 kg/m^3 for uncompacted refuse means that during this period the leachate produced 7.83×10^{-8} g P/l refuse. Note that phosphorus continues to leach from the lysimeter. If one assumes a phosphorus content of 1.3 mg/gm (calculated from Fungaroli and Steiner, 1971) then this means that some 0.9 percent of the phosphorus has been leached during this period. It is notable that a second lysimeter left exposed to the natural weather of Southern California failed to produce any leachate at all when there was a natural rainfall of 38 cm/year.

Some more definitive figures of the phosphorus production from saturated sanitary landfills can be obtained from later work in this area. Fungaroli and Steiner (1971) studied leachate composition from refuse in laboratory lysimeters which were 0.56 m^2 square and contained 2.44 m refuse with a 0.61 m soil cover. The lysimeters were not saturated. At the start of the experiment and during 452 days, 49.5 l leachate was collected. This leachate contained 0.36 g total phosphorus--a quantity that represented approximately 0.5 percent of the phosphate in the lysimeter. To compute the phosphate loading per kg dry refuse, the following calculations were made:

Volume of refuse = 8.2 m^3
Dry refuse density as placed = 194 kg/m^3

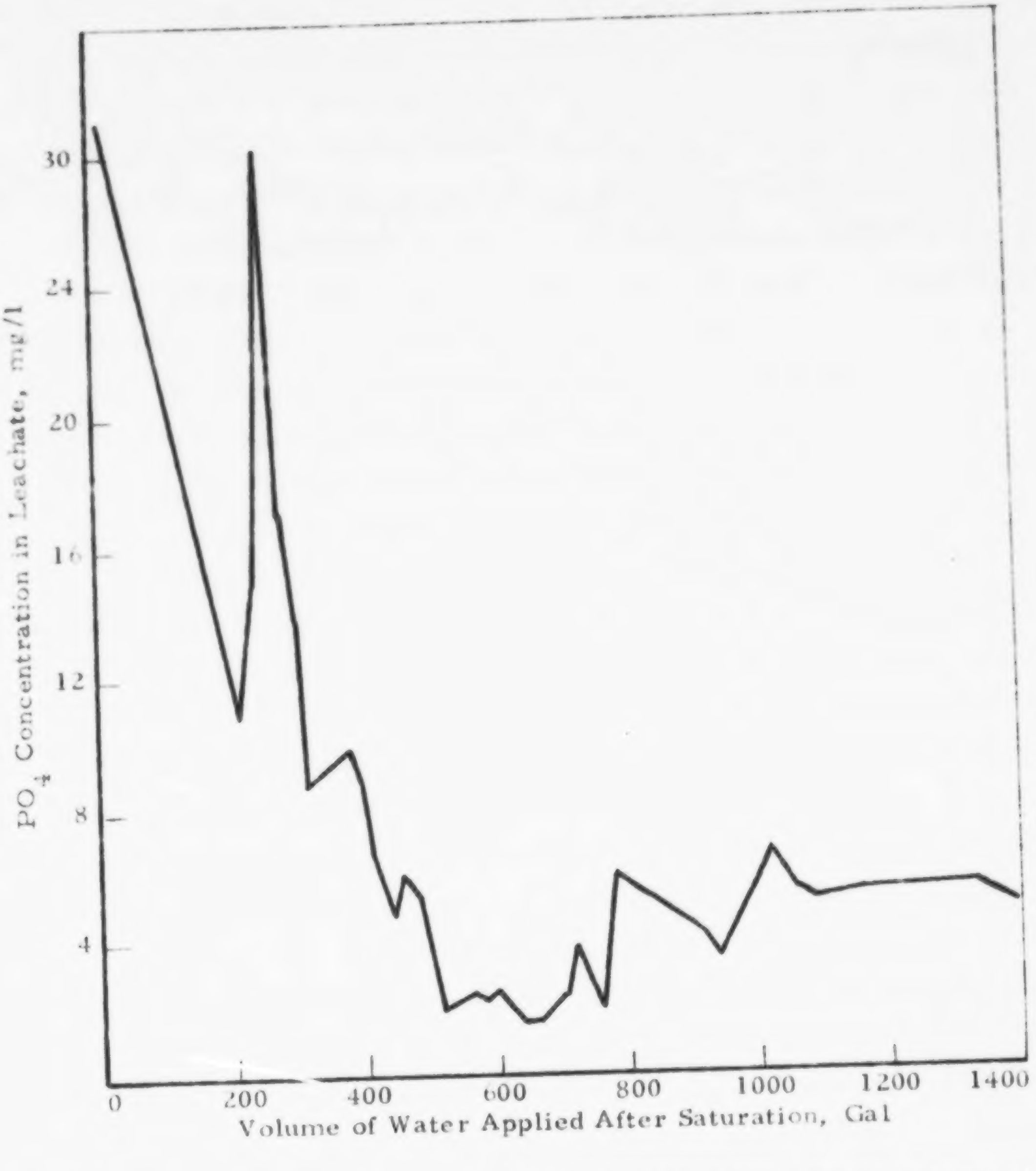


Figure B-1. Phosphate concentration in leachate from water-saturated refuse (uncompacted vol. = 9 m^3 (320 ft^3)), after Merz, (1954).

∴ total dry refuse as placed = $8.2 \times 194 = 1590$ kg

Total leachate contained 0.36 g P

∴ P loading in leachate $= \dfrac{0.36 \text{ g P}}{1590 \text{ kg refuse}}$

$= 0.226 \times 10^{-6}$ P/g refuse

Pohland (1972) conducted lysimeter studies on refuse containing 50 percent paper, 25 percent garbage, 7 percent glass, 5 percent rags, 5 percent stone and sand, 4 percent metal, 3 percent plastic, and 1 percent wood. About 1270 kg of this synthetic refuse were placed in bins to an initial uncompacted depth of 3 m and covered with 76 cm soil and then sod to produce even distribution of water. The refuse was then saturated with 950 l water and leachate collected over 312 days. This leachate contained 1.06 g P which amounts to a phosphorus loss per g of uncompacted refuse of about 0.85×10^{-6} g P/g.

It is notable that in Pohland's experiments a parallel lysimeter was used in which leachate was recycled. During the 312 day experimental period the net production of phosphorus from this lysimeter was nil. This might well be considered as a control procedure for this source of phosphorus; of course, the length of the experiment was less than one year and phosphorus may eventually break through even with leachate recycle through the landfill.

Armentrout and Bortner (1971) in what appears to be a pilot experiment to that of Pohland (1972) placed 3.1 m^3 refuse in a 4.3 m cylinder and placed a soil cover over it. The refuse was compacted, assuming a density of 318 kg/m^3, the weight of compacted refuse would be

$3.1 \times 318 = 985$ kg

The fill was saturated and in 11 weeks approximately 2.03 m water were applied, generating 165 l leachate with an average phosphorus concentration of 9.1 mg/l. This amounts to a phosphorus output of

$$\frac{165\ \mathrm{l} \times 0.0091\ \mathrm{g/l}}{985000\ \mathrm{g}} = 1.53 \times 10^{-6}\ \mathrm{g\ P/g\ refuse}$$

Again in these experiments a parallel leachate recycle lysimeter was run with a resultant phosphorus concentration of 0.21 mg/l compared with the 9.1 mg/l found in the lysimeter leachate without recycle.

The figures for phosphorus loadings from refuse in laboratory lysimeters are summarized below in Table B-2. These figures are consistent if one examines the pattern of phosphorus release from landfills as shown by the work of Merz (1954) in Figure B-1. Initially there are high concentrations of phosphorus in leachate which gradually decrease. Fungaroli and Steiner's experiments were on unsaturated refuse and short circuiting may have occurred thus causing a lesser concentration. Armentrout and Bortner's experiments and those of Pohland commenced after the landfill was saturated. The shorter duration experiments of Armentrout and Bortner included more of the initial high phosphate release than the longer term experiments of Pohland and therefore the former workers' phosphate leachate loadings are higher. The extremely low values of Merz (1954) cannot be explained at this time.

One must conclude that the loadings of phosphate in leachate from sanitary landfill will be variable, depending on the degree of saturation and the age of the fill. However, excluding the results calculated from Merz, the range of values (0.226 to 1.53 μg P/g refuse) is not vastly different.

Actual runoff concentrations may, however, not be easily related to these values. Hence, runoff concentrations from an open dump were used in the mass flow computer program (Silvey, 1970); this allowed relating the output from solid wastes to the area of waste and the rainfall.

Table B-2. COMPARATIVE P LOADINGS IN LEACHATES FROM EXPERIMENTAL LANDFILLS

Investigator	Landfill Saturated	Duration of Experiment, days	P loading in leachate, μg P/g refuse
Fungaroli and Steiner (1971)	No	452	0.226
Pohland (1972)	Yes	312[a]	0.85
Armentrout and Bortner (1971)	Yes	77[a]	1.53
Merz (1954)	Yes	365[a]	0.0783

[a] After saturation

APPENDIX C

PHOSPHORUS MASS FLOW PROGRAM

```
FILE  5=INPUT
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON /CIDE/DPFAC
      COMMON /MINE/XMACRE,XMCONC,XMFAC
      COMMON/FERG/SLOPH,RAIN,FERT(12),FACRE
      COMMON/FER/ORA
      COMMON/IRR/FLOW(12)
      COMMON/ANIM/COWS(12),CHICK(12),PIGS(12),SHEEP(12)
      COMMON/ANIC/CHW(4,11),FEFD
      COMMON/DETER/PHP(2),PLP(2),PNP(2),PSO(2),DPOP(2),SFAC2(2)
      COMMON/MON/M
      COMMON /DUST/DMFLO,DMCONC,DMTL,DPMFLO,DPMIN,DWSFLO,DFWT(12),DFCONC
     1,DFUSE
      COMMON/SOLID/SACRE,SCONC
      COMMON /URBAN/UACRE,UCONC,UFAC
      COMMON /NATURE/XNACRE,XNCONC,XOACRE
      COMMON/NAT/XFACRE,GACRE
      COMMON/RIV/RFLO,RCONC,DFAC,DDFAC
      COMMON/COM1/RFCONC
      COMMON/COM2/PCOW,PCHIC,PPIGS,PSHEP
      COMMON/COM3/IRT(7),X(11),RJAN,XLIQ,AU,SLOD,XL,RLS,AT,RZ,BSOL
      COMMON/COM4/FXD,FXF,FXG
      COMMON/COM5/R,SK,C,P,FA1,FA2,FA3,FL1,FL2,FL3
      COMMON/COM6/PHPPC,PLPPC,PNPPC,PSOPC,PLBHP,PLBLP,PLBNP,PLBSO
      COMMON/COM7/ERATE
      DIMENSION BOF(7),D(7),ITYPA(15),ITYPB(15),ITYPC(15),ITYPD(15),E(7)
      DIMENSION T(60),EOT(7),PROC(17)
      DIMENSION FFAC(100),COS3(100),IY3(100),P3(100),XB2(100),FLOU(100)
      DATA D(1)/.078/,D(2)/.051/,D(3)/.026/,D(4)/.020/,D(5)/.013/,D(6)/.
     1010/,D(7)/.008/
      DATA PROC(6)/6HCOAG  /,PROC(10)/6HREV OS/,PROC(11)/6HION EX/,PROC(
     116)/6HNO PRO/,PROC(17)/6HNO TRT/,PROC(8)/6HCOAG+C/
```

```
      READ(5,1038) NTYA,NTYB,NTYC,NTYD
      READ(5,1038) (ITYPA(I),I=1,NTYA)
      READ(5,1038) (ITYPB(I),I=1,NTYB)
      READ(5,1038) (ITYPC(I),I=1,NTYC)
      READ(5,1038) (ITYPD(I),I=1,NTYD)
  700 DO 600 I=1,60
      T(I)=0.0
  600 CONTINUE
      DFLAG=0
      TTAL=0.0
      WRITE(6,1040)

   50 READ(5,1000,END=101)(BUF(I),I=1,7)
      WRITE(6,1041)(BUF(I),I=1,7)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23
     1,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45
     2,46,47,48,49) BUF(1)
  101 DFLAG=1
      GO TO 100
    1 DO 60 I=1,6
      PRATE(I)=BUF(I+1)
   60 CONTINUE
      GO TO 50
    2 DO 61 I=7,12
      PRATE(I)=BUF(I-5)
   61 CONTINUE
      GO TO 50
    3 FAC1=BUF(2)
      FAC2=BUF(3)
      FAC3=BUF(4)
      FAC4=BUF(5)
      FAC5=BUF(6)
      FAC6=BUF(7)
      GO TO 50
    4 FAC7=BUF(2)
      FLO1=BUF(3)
      FLO2=BUF(4)
      RFCONC=BUF(5)
      RJAN=BUF(6)
      GO TO 50
    5 DO 64 I=1,6
      FERT(I)=BUF(I+1)
   64 CONTINUE
      GO TO 50
    6 DO 65 I=7,12
      FERT(I)=BUF(I-5)
   65 CONTINUE
      GO TO 50
    7 DO 66 I=1,6
      FLOW(I)=BUF(I+1)
```

```
66 CONTINUE
   GO TO 50
 8 DO 67 I=7,12
   FLOW(I)=BUF(I-5)
67 CONTINUE
   GO TO 50
 9 DO 68 I=1,6
   COWS(I)=BUF(I+1)
68 CONTINUE
   GO TO 50
10 DO 69 I=7,12
   COWS(I)=BUF(I-5)
69 CONTINUE
   GO TO 50
11 DO 70 I=1,6
   CHICK(I)=BUF(I+1)
70 CONTINUE
   GO TO 50
12 DO 71 I=7,12
   CHICK(I)=BUF(I-5)
71 CONTINUE
   GO TO 50
13 DO 72 I=1,6
   PIGS(I)=BUF(I+1)
72 CONTINUE
   GO TO 50
14 DO 73 I=7,12
   PIGS(I)=BUF(I-5)
73 CONTINUE
   GO TO 50
15 DO 74 I=1,6
   SHEEP(I)=BUF(I+1)
74 CONTINUE
   GO TO 50
16 DO 75 I=7,12
   SHEEP(I)=BUF(I-5)
75 CONTINUE
   GO TO 50
17 DO 76 I=1,6
   CWW(1,I)=BUF(I+1)
76 CONTINUE
   GO TO 50
18 DO 77 I=7,11
   CWW(1,I)=BUF(I-5)
77 CONTINUE
   GO TO 50
19 DO 78 I=1,6
   CWW(2,I)=BUF(I+1)
78 CONTINUE
   GO TO 50
```

```
20 DO 79 I=7,11
   CWW(2,I)=BUF(I-5)
79 CONTINUE
   GO TO 50
21 DO 80 I=1,6
   CWW(3,I)=BUF(I+1)
80 CONTINUE
   GO TO 50
22 DO 81 I=7,11
   CWW(3,I)=BUF(I-5)
81 CONTINUE
   GO TO 50
23 DO 82 I=1,6
   CWW(4,I)=BUF(I+1)
82 CONTINUE
   GO TO 50
24 DO 83 I=7,11
   CWW(4,I)=BUF(I-5)
83 CONTINUE
   GO TO 50
25 DO 84 I=1,6
   DFWI(I)=BUF(I+1)
84 CONTINUE
   GO TO 50
26 DO 85 I=7,12
   DFWI(I)=BUF(I-5)
85 CONTINUE
   GO TO 50
27 XMACRE=BUF(2)
   XMCONC=BUF(3)
   XMFAC=BUF(4)
   SLOPH=BUF(5)
   RAIN=BUF(6)
   FACRE=BUF(7)
   GO TO 50
28 PHP(1)=BUF(2)
   PLP(1)=BUF(3)
   PNP(1)=BUF(4)
   PSO(1)=BUF(5)
   SFAC2(1)=BUF(6)
   DPOP(1)=BUF(7)
   CAP=BUF(7)
   GO TO 50
29 PHP(2)=BUF(2)
   PLP(2)=BUF(3)
   PNP(2)=BUF(4)
   PSO(2)=BUF(5)
   SFAC2(2)=BUF(6)
   GO TO 50
30 DMFEO=BUF(2)
   DMCONC=BUF(3)
```

```
      DMTL=BUF(4)
      DPMFLO=BUF(5)
      DPMIN=BUF(6)
      DWSFLO=BUF(7)
      GO TO 50
   31 DFCONC=BUF(4)
      DFUSE=BUF(5)
      DPFAC=BUF(6)
      SFAC=BUF(7)
      GO TO 50
   32 SACRE=BUF(2)
      SCONC=BUF(3)
      UACRE=BUF(5)
      UCONC=BUF(6)
      UFAC=BUF(7)
      GO TO 50
   33 XNACRE=BUF(2)
      XNCONC=BUF(3)
      XDACRE=BUF(5)
      RWACRE=BUF(6)
      WACRE=BUF(7)
      GO TO 50
   34 XFACRE=BUF(2)
      DFAC=BUF(3)
      GACRE=BUF(4)
      RFLO=BUF(5)
      RCONC=BUF(6)
      DDFAC=BUF(7)
      GO TO 50
   35 PCON=BUF(2)
      PCHIC=BUF(3)
      PPIGS=BUF(4)
      PSHEP=BUF(5)
      PHPPC=BUF(6)
      PLPPC=BUF(7)
      GO TO 50
   36 PNPPC=BUF(2)
      PSUPC=BUF(3)
      PLBHP=BUF(4)
      PLBLP=BUF(5)
      PLBMP=BUF(6)
      PLBSO=BUF(7)
      GO TO 50
   37 DO 36 I=1,6
      TRT(I)=BUF(I+1)
   36 CONTINUE
      GO TO 50
   38 TRT(7)=BUF(2)
      DO 67 I=1,5
      X(I)=BUF(I+2)
```

```
 87 CONTINUE
    GO TO 50
 39 DO 88 I=6,11
    X(I)=BUF(I-4)
 88 CONTINUE
    GO TO 50
 40 XLIU=BUF(2)
    AU=BUF(3)
    SLDD=BUF(4)
    XL=BUF(5)
    RLS=BUF(7)
    GO TO 50
 41 AT=BUF(2)
    RZ=BUF(4)
    BSOL=BUF(6)
    FXD=BUF(7)
    GO TO 50
 42 FXF=BUF(2)
    FXG=BUF(3)
    R=BUF(4)
    SK=BUF(5)
    C=BUF(6)
    P=BUF(7)
    GO TO 50
 43 FA1=BUF(2)
    FA2=BUF(3)
    FA3=BUF(4)
    FL1=BUF(5)
    FL2=BUF(6)
    FL3=BUF(7)
    GO TO 50
 44 TT1=BUF(2)
    TT2=BUF(3)
    TT3=BUF(4)
    TT4=BUF(5)
    DRA=BUF(6)
    BASF=BUF(7)
    GO TO 50
 45 NN=BUF(2)
    READ(5,1060)(FFAC(L),L=1,NN)
    WRITE(6,1062)(FFAC(L),L=1,NN)
    GO TO 50
 46 CONTINUE
 47 CONTINUE
 48 CONTINUE
    GO TO 50
 49 CONTINUE
100 DO 200 M=1,12
    CALL PEST(OPOUT)
```

```
      CALL MINSI(XMOUT)
      CALL FRTLZR(FOUT,TORP,TXINP,TISP)
      CALL IRRRF(RFOUT)
      CALL ANMAN(COUT,CHOUT,POUT,SHOUT)
      CALL ANWSI(COUT,1,CNOUT)
      CALL ANWSI(CHOUT,2,HNOUT)
      CALL ANWSI(POUT,3,PNOUT)
      CALL ANWSI(SHOUT,4,SNOUT)
      CALL DOWSI(DOUT,SEPD,DOUTD)
      CALL DTERG(1,DTOUT,SEPT,SDD)
      CALL DTERG(2,DDTOUT,SEPDD,SDI)
      CALL INDUST(DMOUT,DMTLO,DPMOUT,DWSOUT,DFOUT,DSUM)
      DSUMM=DDTOUT+DSUM
      CALL SOLWST(SWOUT)
      CALL URBOFF(UOUT)
      CALL RFALL(RAFO)
      CALL RIVR(RIVER)
      CALL NATIN(XNAT,XDEV,XFOR,XGRA,XNOUT)
      SURB=FAC1*UOUT
      USURB=UOUT-SURB
      DON=DDTOUT+DWSOUT+DMOUT
      SIND=DON*FAC2
      USIND=DON-SIND
      BOB=DMTLO*FAC3
      WALK=DMTLO-BOB
      CON1=(DMTLO/FLO1)*1000.0
      POM=TT1*CON1
      CALL TREAT(CON1,FLO1,NTYA,ITYPA,POM,ITY1,PO1,COST1)
      PDS1=(PO1*FLO1)/1000.0
      POR=WALK+PDS1
      SPOR=POR*FAC4
      UPOR=POR-SPOR
      BILL=DFOUT*FAC5
      GREN=DFOUT-BILL
      CON2=(DFOUT/FLO2)*1000.0
      POM=TT2*CON2
      CALL TREAT(CON2,FLO2,NTYB,ITYPB,POM,ITY2,PO2,COST2)
      PDS2=(PO2*FLO2)/1000.0
      CEL=GREN+PDS2
      SCEL=CEL*FAC6
      UCEL=CEL-SCEL
      DOMIN=DOUT+DTOUT+SURB+SIND+SPOR+SCEL
      FLO3=1.38E5*SFAC*CAP
      FLO4=UACRE*PRATE(M)*UFAC*FAC1*0.001
      FLO5=CAP*BASF*FAC2
      FLO6=FLO1*FAC4+FLO2*FAC6+FLO3+FLO4+FLO5
      FLO7=UPMFLO
      CON3=(DOMIN/FLO6)*1000.0
      POM=TT3*CON3
      FTOT=0.0
      DO 710 K=1,NN
      FTOT=FTOT+FFAC(K)
  710 CONTINUE
      IF(FTOT.LT.1.001.AND.FTOT.GT.0.999) GO TO 711
      WRITE(6,1056) FTOT
      TOMIN=1.0E20
      GO TO 713
  711 TOMIN=0
      COST3=0
      DO 712 I=1,NN
      FLOT=FLO6*FFAC(I)
      FLO3(I)=FLOT
      CALL TREAT(CON3,FLOT,NTYC,ITYPC,POM,ITY3,PO3,COS)
      TOMIN=TOMIN+(PO3*FLOT)/1000.0
      COST3=COST3+COS
      COS3(I)=COS
      IY3(I)=ITY3
      P3(I)=PO3
  712 CONTINUE
  713 SMIN=DPMOUT*FAC7
      UMIN=DPMOUT-SMIN
      CON4=(DPMOUT/FLO7)*1000.0
      POM=TT4*CON4
      CALL TREAT(CON4,FLO7,NTYD,ITYPD,POM,ITY4,PO4,COST4)
      PDS4=(PO4*FLO7)/1000.0
      EFFP=DPOUT+XMOUT+FOUT+RFOUT+CNOUT+HNOUT+PNOUT+SNOUT+SWOUT+XNOUT+US
     1URB+USIND+UPOR+UCEL+TOMIN+RAFO+PDS4+UMIN+RIVER+DOUTD+SDD
      TOTAL=DPOUT+XMOUT+FOUT+RFOUT+COUT+CHOUT+POUT+SHOUT+DOUT+DTOUT+DSUM
     1M+SWOUT+DOOT+XNOUT+RAFO+RIVER+DOUTD+SDD
      AEFFP=XMOUT+TISP+RFOUT+RJAN*(CNOUT+HNOUT+PNOUT+SNOUT)+SWOUT+XNOUT+
     1RAFO+TOMIN+PDS4+USURB+USIND+UPOR+UCEL+UMIN+RIVER*0.5+DOUTD+SDD
      TTAL=TTAL+TOTAL
      X1=DPOUT/TOTAL
      X2=XMOUT/TOTAL
      X3=FOUT/TOTAL
      X4=RFOUT/TOTAL
      X5=COUT/TOTAL
      X6=CHOUT/TOTAL
      X7=POUT/TOTAL
      X8=SHOUT/TOTAL
      X9=DOUT/TOTAL
      X10=DTOUT/TOTAL
      X11=DOTOUT/TOTAL
      X12=DMOUT/TOTAL
      X13=DMTLO/TOTAL
      X14=DPMOUT/TOTAL
      X15=DWSOUT/TOTAL
      X16=DFOUT/TOTAL
      X17=DOMIN/TOTAL
      X18=DSUMM/TOTAL
      X19=SWOUT/TOTAL
```

```
X20=UOUT/TOTAL
X21=XNOUT/TOTAL
X22=RAFU/TOTAL
X23=DPOUT/EFFP
X24=XMOUT/EFFP
X25=FOUT/EFFP
X26=RFOUT/EFFP
X27=CNOUT/EFFP
X28=HNOUT/EFFP
X29=PNOUT/EFFP
X30=SNOUT/EFFP
X31=SHOUT/EFFP
X32=XNOUT/EFFP
X33=USURB/EFFP
X34=USIND/EFFP
X35=UPOR/EFFP
X36=UCEL/EFFP
X37=TUMIN/EFFP
X38=RAFU/EFFP
X39=PUS4/EFFP
X40=UMIN/EFFP
X41=XNAT/EFFP
X42=XNAT/TOTAL
X43=XDEV/EFFP
X44=XDEV/TOTAL
X45=XFOR/EFFP
X46=XFOR/TOTAL
X47=XGRA/EFFP
X48=XGRA/TOTAL
X49=RIVER/EFFP
X50=RIVER/TOTAL
X51=DOUTD/EFFP
X52=DOUTD/TOTAL
X53=SUD/EFFP
X54=SUD/TOTAL
X55=AEFFP/EFFP
X56=TORP/EFFP
X57=TORP/TOTAL
X58=TXINP/EFFP
X59=TXINP/TOTAL
X60=TISP/EFFP
X61=TISP/TOTAL
X62=XMOUT/AEFFP
X63=TISP/AEFFP
X64=RFOUT/AEFFP
X65=RJAN*CNOUT/AEFFP
X66=RJAN*HNOUT/AEFFP
X67=RJAN*PNOUT/AEFFP
X68=RJAN*SNOUT/AEFFP
X69=SHOUT/AEFFP
```

```
      X70=XNOUT/AEFFP
      X71=RAFU/AEFFP
      X72=TDMIN/AEFFP
      X73=PDS4/AEFFP
      X74=USURB/AEFFP
      X75=USIND/AEFFP
      X76=UPOR/AEFFP
      X77=UCEL/AEFFP
      X78=UMIN/AEFFP
      X79=RIVER/AEFFP
      X80=AEFFP/TOTAL
      X81=EFFP/TOTAL
      DO 295 I=1,NN
      X82(I)=(CON3-P3(I))/CON3
  295 CONTINUE
      T(1)=T(1)+DPOUT
      T(2)=T(2)+XMOUT
      T(3)=T(3)+FOUT
      T(4)=T(4)+RFOUT
      T(5)=T(5)+CNOUT
      T(6)=T(6)+HNOUT
      T(7)=T(7)+PNOUT
      T(8)=T(8)+SNOUT
      T(9)=T(9)+SWOUT
      T(10)=T(10)+XNOUT
      T(11)=T(11)+RAFU
      T(12)=T(12)+DOUT
      T(13)=T(13)+DTOUT
      T(14)=T(14)+DOTOUT
      T(15)=T(15)+DMOUT
      T(16)=T(16)+DMTLO
      T(17)=T(17)+DPMOUT
      T(18)=T(18)+DWSOUT
      T(19)=T(19)+DFOUT
      T(20)=T(20)+DSUM
      T(21)=T(21)+DSUMM
      T(22)=T(22)+UOUT
      T(23)=T(23)+USURB
      T(24)=T(24)+USIND
      T(25)=T(25)+UPOR
      T(26)=T(26)+UCEL
      T(27)=T(27)+TDMIN
      T(28)=T(28)+PDS4
      T(29)=T(29)+UMIN
      T(30)=T(30)+COUT
      T(31)=T(31)+CHOUT
      T(32)=T(32)+POUT
      T(33)=T(33)+SHOUT
      T(34)=T(34)+SEPO
      T(35)=T(35)+SEPT
      T(36)=T(36)+TOTAL
```

```
T(37)=T(37)+EFFP
T(38)=T(38)+XNAT
T(39)=T(39)+XDEV
T(40)=T(40)+XFOR
T(41)=T(41)+XGRA
T(42)=T(42)+TURP
T(43)=T(43)+TXINP
T(44)=T(44)+TISP
T(45)=T(45)+RIVER
T(46)=T(46)+DOUTD
T(47)=T(47)+SOD
T(48)=T(48)+AEFFP
IF(M.LT.12) GO TO 200
WRITE(6,1040)
WRITE(6,1043) M
WRITE(6,1001) DPOUT,X1,X23,T(1)
WRITE(6,1002) XMOUT,X2,X24,X62,T(2)
WRITE(6,1003) SLOPM,FOUT,X3,X25,T(3)
WRITE(6,1064) ERATE
WRITE(6,1048) TURP,X57,X56,T(42)
WRITE(6,1049) TXINP,X59,X58,T(43)
WRITE(6,1050) TISP,X61,X60,X63,T(44)
WRITE(6,1004) RFOUT,X4,X26,X64,T(4)
WRITE(6,1009) SWOUT,X19,X31,X69,T(9)
WRITE(6,1010) XNOUT,X21,X32,X70,T(10)
WRITE(6,1044) XNAT,X42,X41,T(38)
WRITE(6,1045) XDEV,X44,X43,T(39)
WRITE(6,1046) XFOR,X46,X45,T(40)
WRITE(6,1047) XGRA,X48,X47,T(41)
WRITE(6,1011) RAFU,X22,X38,X71,T(11)
WRITE(6,1051) RIVER,X49,X50,X79,T(45)
WRITE(6,1052) DOUTD,X51,X52,T(46)
WRITE(6,1053) SOD,X53,X54,T(47)
WRITE(6,1012) DOUT,X9,T(12)
WRITE(6,1013) DTOUT,X10,T(13)
WRITE(6,1022) UOUT,X20,T(22)
WRITE(6,1014) DOTOUT,X11,T(14)
WRITE(6,1015) DMOUT,X12,T(15)
WRITE(6,1018) DWSOUT,X15,T(18)
WRITE(6,1016) DMTLO,X13,T(16)
WRITE(6,1019) DFOUT,X16,T(19)
WRITE(6,1017) DPMOUT,X14,T(17)
WRITE(6,1020) DOMIN,X17,T(20)
WRITE(6,1021) DSUMM,X18,T(21)
WRITE(6,1030) COUT,X5,T(30)
WRITE(6,1031) CHOUT,X6,T(31)
WRITE(6,1032) POUT,X7,T(32)
WRITE(6,1033) SHOUT,X8,T(33)
WRITE(6,1056) POS1,PROC(ITY1),COST1
WRITE(6,1057) POS2,PROC(ITY2),COST2
```

```
      WRITE(6,1036) TOTAL,T(36)
      WRITE(6,1005) CNOUT,X27,X65,T(5)
      WRITE(6,1006) HNOUT,X28,X66,T(6)
      WRITE(6,1007) PNOUT,X29,X67,T(7)
      WRITE(6,1008) SNOUT,X30,X68,T(8)
      WRITE(6,1023) USORM,X33,X74,T(23)
      WRITE(6,1024) USIND,X34,X75,T(24)
      WRITE(6,1025) UPOR,X35,X76,T(25)
      WRITE(6,1026) UCEL,X36,X77,T(26)
      WRITE(6,1027) TOMIN,X37,X72,T(27),COST3
      WRITE(6,1028) POS4,X39,X73,T(28),PROC(ITY4),COST4
      WRITE(6,1029) OMIN,X40,X78,T(29)
      WRITE(6,1037) EFFP,X81,T(37)
      WRITE(6,1054) AEFFP,X80,X55,T(48)
      WRITE(6,1034) SEPD,T(34)
      WRITE(6,1035) SEPT,T(35)
      PLOAD=EFFP*10.0**7/RWACRE
      DO 300 I=1,7
      E(I)=D(I)*PLOAD
  300 CONTINUE
      WRITE(6,1039)(E(N),N=1,7)
      PLOAD=AEFFP*10.0**7/RWACRE
      DO 400 I=1,7
      EUT(I)=D(I)*PLOAD
  400 CONTINUE
      WRITE(6,1055)(EUT(N),N=1,7)
      WRITE(6,1040)
      WRITE(6,1061)
      DO 430 I=1,NN
      MMM=IY3(I)
      WRITE(6,1059) I,FLOO(I),CON3,P3(I),X82(I),COS3(I),PROC(MMM)
  430 CONTINUE
      COAL=0.0
      FALL=0.0
      DO 440 I=1,NN
      FALL=FLOO(I)+FALL
      COAL=COS3(I)+COAL
  440 CONTINUE
      WRITE(6,1063) FALL,COAL
  200 CONTINUE
      SLOPH=500.0
      IF(JFLAG.EQ.0) GO TO 700
      STOP
 1000 FORMAT(I2,6E13.2)
 1001 FORMAT(21H ORGANO PHOS PEST    ,5X,F16.2,2F13.4,F31.2)
 1002 FORMAT(21H STRIP MINE + TAILING,5X,F16.2,3F13.4,F18.2)
 1003 FORMAT(19H FERT RUNOFF(SLOPH=,F6.2,2H) ,F15.2,2F13.4,F31.2)
 1004 FORMAT(21H IRR RETURN FLOW P   ,5X,F16.2,3F13.4,F18.2)
 1005 FORMAT(21H COW AFTER TREAT     ,5X,F16.2,F26.4,F13.4,F18.2)
 1006 FORMAT(21H CHICK AFTER TREAT   ,5X,F16.2,F26.4,F13.4,F18.2)
```

```
1007 FORMAT(21H PIG AFTER TREAT      ,5X,F16.2,F26.4,F13.4,F18.2)
1008 FORMAT(21H SHEEP AFTER TREAT    ,5X,F16.2,F26.4,F13.4,F18.2)
1009 FORMAT(21H SOLID WASTE OUT      ,5X,F16.2,3F13.4,F18.2)
1010 FORMAT(21H NAT DEV RUNOFF       ,5X,F16.2,3F13.4,F18.2)
1011 FORMAT(21H RAINFALL             ,5X,F16.2,3F13.4,F18.2)
1012 FORMAT(21H SEWERED DOMESTIC     ,5X,F16.2,F13.4,F44.2)
1013 FORMAT(21H SEW DOM, DET P       ,5X,F16.2,F13.4,F44.2)
1014 FORMAT(21H IND DETER OUT        ,5X,F16.2,F13.4,F44.2)
1015 FORMAT(21H MISC P OUT           ,5X,F16.2,F13.4,F44.2)
1016 FORMAT(21H METAL FIN OUT        ,5X,F16.2,F13.4,F44.2)
1017 FORMAT(21H MINING P OUT         ,5X,F16.2,F13.4,F44.2)
1018 FORMAT(21H WATER SOFTENING      ,5X,F16.2,F13.4,F44.2)
1019 FORMAT(21H FOOD WASTE OUT       ,5X,F16.2,F13.4,F44.2)
1020 FORMAT(21H MUN TREAT INFLUENT   ,5X,F16.2,F13.4,F44.2)
1021 FORMAT(21H IND DET + OTHER IND  ,5X,F16.2,F13.4,F44.2)
1022 FORMAT(21H URBAN RUNOFF         ,5X,F16.2,F13.4,F44.2)
1023 FORMAT(21H UNSEWER URB.         ,5X,F16.2,F26.4,F13.4,F18.2)
1024 FORMAT(21H UNSEWER IND.         ,5X,F16.2,F26.4,F13.4,F18.2)
1025 FORMAT(21H UNTREATED METALS     ,5X,F16.2,F26.4,F13.4,F18.2)
1026 FORMAT(21H UNTREATED FOODS      ,5X,F16.2,F26.4,F13.4,F18.2)
1027 FORMAT(21H TREAT PLANT EFF      ,5X,F16.2,F26.4,F13.4,F18.2,4X,F2
    12)
1028 FORMAT(21H TREAT P MINING EFF   ,5X,F16.2,F26.4,F13.4,F18.2,4X,AC
    115.2)
1029 FORMAT(21H UNTREATED MINING     ,5X,F16.2,F26.4,F13.4,F13.2)
1030 FORMAT(21H COW MANURE OUT       ,5X,F16.2,F13.4,F44.2)
1031 FORMAT(21H CHICK MANURE OUT     ,5X,F16.2,F13.4,F44.2)
1032 FORMAT(21H PIG MANURE OUT       ,5X,F16.2,F13.4,F44.2)
1033 FORMAT(21H SHEEP MANURE OUT     ,5X,F16.2,F13.4,F44.2)
1034 FORMAT(21H DOM SEPTIC TANK      ,5X,F16.2,F57.2)
1035 FORMAT(21H DET SEPTIC TANK      ,5X,F16.2,F57.2,/)
1036 FORMAT(21H UNTREATED TOTAL      ,5X,F16.2,F57.2,/)
1037 FORMAT(21H TREATED TOTAL        ,5X,F16.2,F13.4,F44.2,/)
1038 FORMAT(15I5)
1039 FORMAT(22H EUTROPHICATION (EFF) ,7F14.4)
1040 FORMAT(1H1)
1041 FORMAT(1X,I2,6E15.3)
1043 FORMAT(2X,9HPARAMETER,5X,8HY E A R ,I2, 6X,10HAMT (G/YR),6X,7HP
    1TAL,8X,5HP EFF,7X,6HP AEFF,7X,11HACCUMULATED, 9H  TR PROC, 8X,4
    2ST,/)
1044 FORMAT(21H    NATURAL RUNOFF    ,5X,F16.2,2F13.4,F31.2)
1045 FORMAT(21H    DEVELOP RUNOFF    ,5X,F16.2,2F13.4,F31.2)
1046 FORMAT(21H    MAN. FOR. RUNOFF  ,5X,F16.2,2F13.4,F31.2)
1047 FORMAT(21H    GRAZING RUNOFF    ,5X,F16.2,2F13.4,F31.2)
1048 FORMAT(21H    ORG PHOSPHORUS    ,5X,F16.2,2F13.4,F31.2)
1049 FORMAT(21H    INORG PHOSPHORUS  ,5X,F16.2,2F13.4,F31.2)
1050 FORMAT(21H    DRAIN PHOSPHORUS  ,5X,F16.2,3F13.4,F18.2)
1051 FORMAT(21H RIVER                ,5X,F16.2,3F13.4,F18.2)
1052 FORMAT(21H DOM DIRECT DISCHARGE,5X,F16.2,2F13.4,F31.2)
1053 FORMAT(21H DOM DET DIRECT DISCH,5X,F16.2,2F13.4,F31.2)
```

```
1054 FORMAT(21H AVAIL TREATED TOTAL ,5X,F16.2,2F13.4,F31.2,/)
1055 FORMAT(22H EUTROPHICATION (AEFF),/F14.4)
1056 FORMAT(21H IN-PLANT TRT METALS ,5X,F16.2,61X,A6,F15.2)
1057 FORMAT(21H IN-PLANT TRT FOODS  ,5X,F16.2,61X,A5,F15.2)
1058 FORMAT(24H DOM FLOW PERCENT GT 1.0,5X,5HFTOT=,F25.4)
1059 FORMAT(4X,I2,5X,F25.4,5X,F8.2,9X,F8.2,13X,F6.2,/X,F13.2,6X,A6)
1060 FORMAT(10F8.3)
1061 FORMAT(11/1   PLANT                FLOW(L/YR)     INFLUENT(MG/L)
    1 EFFLUENT(MG/L)   P REMOVAL(PERCENT)      COST         PROCESS,/)
1062 FORMAT(1X,10F8.3)
1063 FORMAT(///,8H   TOTAL,F28.4,53X,F16.2)
1064 FORMAT(21H    EROSION RATE     ,5X,F17.3)
     END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


     SUBROUTINE IRRRF(RFOUT)
     COMMON /IRR/FLOW(12)
     COMMON/MON/M
     COMMON/COM1/RFCONC
     RFOUT=FLOW(M)*RFCONC
     RETURN
     END

$$$$$$$.$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


     SUBROUTINE ANMAN(COUT,CHOUT,POUT,SHOUT)
     COMMON /ANIM/COWS(12),CHICK(12),PIGS(12),SHEEP(12)
     COMMON/MON/M
     COMMON/COM2/PCOW,PCHIC,PPIGS,PSHEP
     COUT=PCOW*COWS(M)
     CHOUT=PCHIC*CHICK(M)
     POUT=PPIGS*PIGS(M)
     SHOUT=PSHEP*SHEEP(M)
     RETURN
     END

$$$$$$$.$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


     SUBROUTINE ANWST(AOUT,J,ANOUT)
     COMMON /ANIC/CWW(4,11),FEED
     COMMON/COM3/TRT(7),X(11),RJAN,XLIQ,AU,SLUD,XL,RLS,AT,RZ,BSOL
     XLCH=0.0
     XLDISP=0
     RECW=0
     DO 100 N=1,7
```

```
      IF(CWW(J,N).EQ.0.0) GO TO 100
      XLDISP=XLDISP+CWW(J,N)*AOUT*TRT(N)*X(N)
      RECW=RECW+CWW(J,N)*AOUT*TRT(N)*(1.0-X(N))
  100 CONTINUE
      IF(CWW(J,8).EQ.0.0) GO TO 110
      XLDISP=XLDISP+(CWW(J,8)*AOUT*X(8))*((1.0-XLIQ)*BSOL+XLIQ*AU)
      RECW=RECW+((1.0-X(8))*CWW(J,8)*AOUT)*((1.0-XLIQ)*BSOL+XLIQ*AU)
  110 IF(CWW(J,9).EQ.0.0) GO TO 120
      XLDISP=XLDISP+CWW(J,9)*AOUT*SLOD*XL
      XLCH=XLCH+CWW(J,9)*AOUT*(1.0-SLOD)
  120 IF(CWW(J,10).EQ.0.0) GO TO 130
      XLDISP=XLDISP+CWW(J,10)*AOUT*SLOD*XL
      XLCH=XLCH+CWW(J,10)*AOUT*(1.0-SLOD)
  130 IF(CWW(J,11).EQ.0.0) GO TO 140
      XLDISP=XLDISP+CWW(J,11)*AOUT*SLOD*XL
      XLCH=XLCH+CWW(J,11)*AOUT*(1.0-SLOD)
      RECW=RECW+RLS*XLCH+X(11)*AT*(1.0-RLS)*XLCH
      XLDISP=XLDISP+X(11)*AT*(1.0-RLS)*XLCH
  140 ANOUT=(RECW+RZ*XLDISP)*RJAN
      RETURN
      END

##############################################################

      SUBROUTINE RFALL(RAFO)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON/MON/M
      COMMON /FERG/SLOPH,RAIN,FERT(12),FACRE
      RAFO=PRATE(M)*RAIN*WACRE
      RETURN
      END

##############################################################

      SUBROUTINE DOWST(DOUT,SEPO,DOUTD)
      COMMON/RIV/RFLO,RCONC,DFAC,DOFAC
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      DOUT=CAP*SFAC*795.6
      SEPO=CAP*(1.0-SFAC)*795.6
      DOUTD=DOUT*DFAC
      DOUT=DOUT-DOUTD
      RETURN
      END
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

      SUBROUTINE SOLWST(SWOUT)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON/SOLID/SACRE,SCONC
      COMMON /MON/M
      SWOUT=PRATE(M)*SACRE*SCONC*(PRATE(M)/(PRATE(M)+25.0))
      RETURN
      END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

      SUBROUTINE URBOFF(UOUT)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON /MON/M
      COMMON /URBAN/UACRE,UCONC,UFAC
      UOUT=UACRE*PRATE(M)*UCONC*UFAC
      RETURN
      END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

      SUBROUTINE NATIN(XNAT,XDEV,XFOR,XGRA,XNOUT)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON /NATURE/XNACRE,XNCONC,XDACRE
      COMMON /MON/M
      COMMON/NAT/XFACRE,GACRE
      COMMON/COM4/FXD,FXF,FXG
      F=PRATE(M)*XNCONC*(PRATE(M)/(PRATE(M)+10.0))
      XNAT=XNACRE*F
      XDEV=XDACRE*FXD*F
      XFOR=XFACRE*FXF*F
      XGRA=GACRE*FXG*F
      XNOUT=XNAT+XDEV+XFOR+XGRA
      RETURN
      END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

      SUBROUTINE MINST(XMOUT)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON /MINE/XMACRE,XMCONC,XMFAC
      COMMON /MON/M
      XMOUT=XMACRE*PRATE(M)*XMCONC*XMFAC
      RETURN
      END
```

```
  #################################################################


      SUBROUTINE PEST(OPOUT)
      COMMON /MUN/M
      COMMON/FERG/SLDPH,RAIN,FERT(12),FACRE
      COMMON /CIDE/OPFAC
      OPOUT=FACRE*OPFAC*0.11
      RETURN
      END

  #################################################################


      SUBROUTINE FRTLZR(TOTP,TORP,TXINP,TISP)
      COMMON /FERG/SLDPH,RAIN,FERT(12),FACRE
      COMMON/FER/DRA
      COMMON /MUN/M
      COMMON/COM5/R,SK,C,P,FA1,FA2,FA3,FL1,FL2,FL3
      COMMON/COM7/ERATE
      PLA=(9.0*FERT(M))/(20.0+FERT(M))
      DS=FERT(M)-PLA
      CF=2.27
      SLDPH=SLDPH+DS/CF
      SA=((12.7*SLDPH)/(330.0+SLPH))*CF
      PLA=PLA+SA
      SLDPH=SLDPH-SA/CF+0.25*PLA/CF
      Z=R*SK*C*P*0.0224
      A1=FA1*Z*FL1*0.01044
      A2=FA2*Z*FL2*0.03025
      A3=FA3*Z*FL3*0.08954
      ERATE=A1+A2+A3
      A=0.025*ERATE
      B=ERATE-A
      ORP=A*0.0056
      XINP=B*SLDPH/1000000.0
      TOTP=(ORP+XINP+DRA)*FACRE
      TORP=ORP*FACRE
      TXINP=XINP*FACRE
      TISP=DRA*FACRE
      RETURN
      END
  ######################################################################


      SUBROUTINE INDUST(DMOUT,DMTLO,DPMOUT,DWSOUT,DFOUT,DSUM)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON /MUN/M
      COMMON /DUST/DMFLO,DMCONC,DMTL,DPMFLO,DPMIN,DWSFLO,DFWT(12),DFCONC
     1,DFUSE
      DMOUT=DMFLO*DMCONC*CAP
      DMTLO=DMTL
      DPMOUT=DPMIN*DPMFLO
      DWSOUT=DWSFLO*DMCONC*CAP
      DFOUT=DFWT(M)*DFCONC*DFUSE
      DSUM=DMOUT+DMTLO+DPMOUT+DWSOUT+DFOUT
      RETURN
      END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


      SUBROUTINE DTERG(J,D,S,SD)
      COMMON /GEN/PRATE(12),CAP,WACRE,SFAC
      COMMON /DUST/DMFLO,DMCONC,DMTL,DPMFLO,DPMIN,DWSFLO,DFWT(12),DFCONC
     1,DFUSE
      COMMON/RIV/RFLO,RCONC,DFAC,DDFAC
      COMMON /DETER/PHP(2),PLP(2),PNP(2),PSO(2),DPOP(2),SFAC2(2)
      COMMON/COM6/PHPPC,PLPPC,PNPPC,PSOPC,PLBHP,PLBLP,PLBNP,PLBSO
      DPOP(2)=DMCONC*DDFAC*CAP
      D=(PHP(J)*PHPPC*PLBHP+PLP(J)*PLPPC*PLBLP+PNP(J)*PNPPC*PLBNP+PSO(J)
     1*PSOPC*PLBSO)*DPOP(J)*SFAC2(J)
      S=(D*(1.0-SFAC2(J)))/SFAC2(J)
      SD=D*DFAC
      D=D-SD
      RETURN
      END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


      SUBROUTINE RIVR(RIVER)
      COMMON/RIV/RFLO,RCONC,DFAC,DDFAC
      RIVER=RCONC*RFLO
      RETURN
      END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


      SUBROUTINE TREAT(P,Q,NTYPE,ITYPE,PMAX,ITYPES,PO,COST)
      DIMENSION ITYPE(15),XCOST(15),XPO(15)
      QMGD=Q*7.24E-10
      QMGY=QMGD*365.25
      IF(P.GT. PMAX) GO TO 60
```

```
    PO=P
    COST=0.0
    ITYPES=17
    GO TO 40
 60 ITEST=0
    REM=(P-PMAX)/P
    COST=0.9E20
    DO 20 I=1,NTYPE
    GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15) ITYPE(I)
  1 CONTINUE
    PO=P
    COST=0.0
    ITYPES=17
    GO TO 40
  2 CONTINUE
    GO TO 20
  3 CONTINUE
    GO TO 20
  4 CONTINUE
    GO TO 20
  5 CONTINUE
    GO TO 20
  6 CONTINUE
C  COAGULATION INCLUDING LABOR AND STORAGE
    PMIN6=1.0
    IF(REM.GT.0.951) GO TO 20
    IF(PMAX.LT.PMIN6) GO TO 20
    XPO(I)=PMAX
    IF(REM.GE.0.74) FEP=(REM-0.62)/0.1257
    IF(REM.LT.0.74) FEP=1.0
    DOLC=2.251*P*QMGY*FEP
    X=73.2*FEP*P*QMGD
    IF(X.LE.1000.0) DOLL=5600.0
    IF(X.GT.1000.0.AND.X.LT.6000.0) DOLL=4800.0+33.6*X**0.5935
    IF(X.GE.6000.0) DOLL=2.065*X**0.6792+33.62*X**0.5935
    XCOST(I)=DOLC+DOLL
    GO TO 30
  7 CONTINUE
    GO TO 20
  8 CONTINUE
C  COAGULATION INCLUDING LABOR,STORAGE, AND CAPITAL COSTS
    PMIN8=1.0
    IF(REM.GT.0.951) GO TO 20
    IF(PMAX.LT.PMIN8) GO TO 20
    XPO(I)=PMAX
    IF(REM.GE.0.74) FEP=(REM-0.62)/0.1257
    IF(REM.LT.0.74) FEP=1.0
    DOLC=2.251*P*QMGY*FEP
    X=73.2*FEP*P*QMGD
    IF(X.LE.1000.0) DOLL=5600.0
```

```
      IF(X.GT.1000.0.AND.X.LT.6000.0) DOLL=4800.0+33.6*X**0.5935
      IF(X.GE.6000.0) DOLL=2.065*X**0.6792+33.62*X**0.5935
      DOLP=13600.0*QMGD**0.856
      XCOST(I)=DOLC+DOLL+DOLP
      GO TO 30
    9 CONTINUE
      GO TO 20
   10 CONTINUE
C    REVERSE OSMOSIS
      PMIN10=0.05
      IF(REM.GT.0.991) GO TO 20
      IF(PMAX.LT.PMIN10) GO TO 20
      QADJ=QMGD*((P-0.85*PMAX)/P)
      IF((P-PMAX).LE.20.0) GO TO 21
      XCOST(I)=1.05*QADJ**(-0.3132)
      IF(XCOST(I).LT.0.35) XCOST(I)=0.35
   22 XCOST(I)=XCOST(I)*QADJ*365250.0
      XPO(I)=PMAX
      GO TO 30
   21 XCOST(I)=0.705-0.243*ALOG10(QADJ)
      IF(XCOST(I).LT.0.30) XCOST(I)=0.30
      GO TO 22
   11 CONTINUE
C    SELECTIVE ION EXCHANGE
      PMIN11=0.5
      IF(REM.GT.0.961) GO TO 20
      IF(PMAX.LT.PMIN11) GO TO 20
      IF((P-PMAX).LT.10.0) QADJ=QMGD
      IF((P-PMAX).GE.10.0) QADJ=QMGD*((P-PMAX)/10.0)
      DOLP=19832.0*QADJ**0.92
      DOLL=(0.16*QADJ**(-0.3815)+0.09*QADJ**(-0.2245))*QADJ*365250.0
      XCOST(I)=DOLP+DOLL
      XPO(I)=PMAX
      GO TO 30
   12 CONTINUE
      GO TO 20
   13 CONTINUE
      GO TO 20
   14 CONTINUE
      GO TO 20
   15 CONTINUE
      GO TO 20
   30 IF(XCOST(I).GT.COST) GO TO 20
      COST=XCOST(I)
      ITYPES=ITYPE(I)
      PO=XPO(I)
      ITEST=1
   20 CONTINUE
      IF(ITEST.GT.0) GO TO 40
      PO=P
      COSI=0.0
      ITYPES=16
   40 RETURN
      END
```

APPENDIX D

INPUT AND OUTPUT INFORMATION FOR PHOSPHORUS MASS FLOW PROGRAM

Table D-1. INPUT DATA: EXAMPLE VALUES LISTED IN TABLES D-2, D-3, D-4, FOR HYPOTHETICAL LAKE, LAKE MICHIGAN, AND LAKE ERIE, RESPECTIVELY FOR A GIVEN LINE AND COLUMN

Line	Column	Parameter	Value	Description
1, 2	all	PRATE(I)	cm/yr	annual precipitation
3	1	FAC1	ratio	sewered[a] to total urban runoff
	2	FAC2	ratio	sewered to total for general industrial
	3	FAC3	ratio	in-plant treated metal finishing to total metal finishing
	4	FAC4	ratio	sewered to total metal finishing
	5	FAC5	ratio	in-plant treated food wastes to total food wastes
	6	FAC6	ratio	sewered to total food wastes
4	1	FAC7	ratio	sewered to total mining (phosphorus only) wastes
	2	FLO1	l/yr	liquid flow in metal finishing
	3	FLO2	l/yr	liquid flow in food industry
	4	RFCONC	g/l	mean phosphorus concentration in irrigation return flow
	5	RJAN	ratio	amount of animal waste P which is available for algal growth
5, 6	all	FERT(I)	kg/hectare. yr	fertilizer application rate
7, 8	all	FLOW(I)	l/yr	irrigation return flow
9, 10	all	COWS(I)	number	number of cows and horses
11, 12	all	CHICK(I)	number	number of poultry
13, 14	all	PIGS(I)	number	number of swine
15, 16	all	SHEEP(I)	number	number of sheep and goats
17, 18	all	CWW(1, I)	ratio	distribute animal wastes to eleven treatments, COW
19, 20	all	CWW(2, I)	ratio	distribute animal wastes to eleven treatments, CHICK

Table D-1 (Cont'd)

Line	Column	Parameter	Value	Description
21, 22	all	CWW(3, I)	ratio	distributes animal wastes to eleven treatments, PIGS
23, 24	all	CWW(4, I)	ratio	distributes animal wastes to eleven treatments, SHEEP
25, 26	all	DFWT(I)	g/yr	amount of food processed
27	1	XMACRE	cm^2	area of strip mines and tailings
	2	XMCONC	g/cc	P concentration in runoff from XMACRE
	3	XMFAC	ratio	runoff to total precipitation
	4	SLDPH	ppm	solid phase phosphorus in soils
	5	RAIN	g/cc	P concentration in rainfall
	6	FACRE	cm^2	area of fertilized agriculture
28	1	PHP(1)	ratio	fraction of domestic population using high-P detergents
	2	PLP(1)	ratio	fraction of domestic population using low-P detergents
	3	PNP(1)	ratio	fraction of domestic population using no-P detergents
	4	PSO(1)	ratio	fraction of domestic population using soaps
	5	SFAC2(1)	ratio	sewered to total domestic waste = SFAC
	6	DPOP(1)	number	number of people = CAP
	6	CAP	number	number of people
29	1	PHP(2)	ratio	fraction of industrial population using high-P detergents
	2	PLP(2)	ratio	fraction of industrial population using low-P detergents
	3	PNP(2)	ratio	fraction of industrial population using no-P detergents
	4	PSO(2)	ratio	fraction of industrial population using soaps

Table D-1 (Cont'd)

Line	Column	Parameter	Value	Description
	5	SFAC2(2)	ratio	sewered to total (always 1.0 for industry, see FAC2)
30	1	DMFLO	g/MGD. yr	miscellaneous industrial P use (related to DMCONC)
	2	DMCONC	MGD/capita	industrial consumptive water use per capita
	3	DMTL	g/yr	actual phosphorus used in metal finishing
	4	DPMFLO	m^3/yr	outflow from P mining activities
	5	DPMIN	g/m^3	P concentration in P mining effluents
	6	DWSFLO	g/MGD. yr	water softening P use (related to DMCONC)
31	3	DFCONC	ratio	fraction of food which is phosphorus
	4	DFUSE	ratio	wastage of food materials in processing
	5	OPFAC	$g/cm^2 . yr$	use of organophosphorus pesticides in agriculture
	6	SFAC	ratio	sewered to total domestic waste
32	1	SACRE	cm^2	area devoted to solid waste disposal
	2	SCONC	g/cc	P concentration in runoff from solid wastes
	4	UACRE	cm^2	urban area
	5	UCONC	g/cc	P concentration in urban runoff
	6	UFAC	ratio	runoff to total precipitation
33	1	XNACRE	cm^2	area of natural watershed
	2	XNCONC	g/cc	P concentration in natural watershed runoff
	4	XDACRE	cm^2	developed areas in natural watershed
	5	RWACRE	cm^2	water surface area of lake in question

Table D-1 (Cont'd)

Line	Column	Parameter	Value	Description
	6	WACRE	cm^2	total water surface area in basin
34	1	XFACRE	cm^2	area of managed forest in watershed
	2	DFAC	ratio	fraction of direct discharge of sewered domestic wastes
	3	GACRE	cm^2	area of grazing lands in watersheds
	4	RFLO	l/yr	flow of river entering basin
	5	RCONC	g/l	P concentration in river entering basin
35	1	PCOW	g/number. yr	annual P output per individual cow
	2	PCHIC	g/number. yr	annual P output per individual chicken
	3	PPIGS	g/number. yr	annual P output per individual pig
	4	PSHEP	g/number. yr	annual P output per individual sheep
	5	PHPPC	g/cap. yr	use rate of high P detergent
	6	PLPPC	g/cap. yr	use rate of low P detergent
36	1	PNPPC	g/cap. yr	use rate of no P detergent
	2	PSOPC	g/cap. yr	use rate of soaps
	3	PLBHP	ratio	grams P per gram high P detergent used
	4	PLBLP	ratio	grams P per gram low P detergent used
	5	PLBNP	ratio	grams P per gram no P detergent used
	6	PLBSO	ratio	grams P per gram soap used
37, 38	all, 1	TRT(I)	ratio	phosphorus output per input for seven animal waste treatment schemes

Table D-1 (Cont'd)

Line	Column	Parameter	Value	Description
38 39	2, 5 all	X(I)	ratio	animal waste P distribution: ratio of total applied to land disposal
40	1	XLIQ	ratio	liquid portion of animal waste treated by source separation
	2	AU	ratio	aerobic treatment output from liquids from source separation
	3	SLDD	ratio	P fraction in solids from drying, incineration, and composting
	4	XL	ratio	portion of SLDD disposed on land
	6	RLS	ratio	portion of XLS discharged to receiving water
41	1	AT	ratio	portion of XLS aerobically treated and distributed
	3	RZ	ratio	proportion of land-disposed manure P entering surface water
	5	BSOL	ratio	SOL which is discharged
	6	FXD	ratio	developed watershed runoff P concentration to natural
42	1	FXF	ratio	managed forest watershed P concentration to natural
	2	FXG	ratio	grazing watershed P concentration to natural
	3	R	Not Applicable	erosivity, Universal Soil Loss Equation
	4	SK		soil factor (K), Universal Soil Loss Equation
	5	C	Not Applicable	cropping factor, Universal Soil Loss Equation
	6	P		practice factor, Universal Soil Loss Equation

Table D-1 (Cont'd)

Line	Column	Parameter	Value	Description
43	1	FA1	ratio	area of fertilized agriculture in Slope Class I
	2	FA2	ratio	area of fertilized agriculture in Slope Calss II
	3	FA3	ratio	area of fertilized agriculture in Slope Class III
	4	FL1	ft	mean length of slope in Slope Class I
	5	FL2	ft	mean length of slope in Slope Class II
	6	FL3	ft	mean length of slope in Slope Class III
44	1	TT1	ratio	fraction remaining from treatment of metal finishing wastes
	2	TT2	ratio	fraction remaining from treatment of food wastes
	3	TT3	ratio	fraction remaining from treatment of domestic wastes
	4	TT4	ratio	fraction remaining from treatment of P mining wastes
	5	DRA	$g/cm^2 \cdot yr$	output of soluble orthophosphate from fertilized agriculture
	6	BASF	l/yr. cap	annual industrial consumptive use of water per capita
45	1	NN	number	number of treatment plants in basin
45ff	2ff	FFAC1	ratio	fraction of domestic flow going to each treatment plant

---

[a] Sewered indicates the flow enters the municipal treatment plant (DOMIN)

Table D-2. INPUT DATA FOR HYPOTHETICAL LAKE BASIN (KEYED TO TABLE D-1)

```
 1     .500E+02    .500E+02    .500E+02    .500E+02    .500E+02    .500E+02
 2     .500E+02    .500E+02    .500E+02    .500E+02    .500E+02    .500E+02
 3    0.           .500E+00   0.           .100E+01   0.           .100E+01
 4     .100E+01    .120E+10    .227E+09    .200E-04    .500E+00   0.
 5     .400E+02    .400E+02    .400E+02    .400E+02    .400E+02    .400E+02
 6     .400E+02    .400E+02    .400E+02    .400E+02    .400E+02    .400E+02
 7     .780E+09    .780E+09    .780E+09    .780E+09    .780E+09    .780E+09
 8     .780E+09    .780E+09    .780E+09    .780E+09    .780E+09    .780E+09
 9     .348E+05    .348E+05    .348E+05    .348E+05    .348E+05    .348E+05
10     .348E+05    .348E+05    .348E+05    .348E+05    .348E+05    .348E+05
11     .176E+07    .176E+07    .176E+07    .176E+07    .176E+07    .176E+07
12     .176E+07    .176E+07    .176E+07    .176E+07    .176E+07    .176E+07
13     .720E+05    .720E+05    .720E+05    .720E+05    .720E+05    .720E+05
14     .720E+05    .720E+05    .720E+05    .720E+05    .720E+05    .720E+05
15     .789E+05    .789E+05    .789E+05    .789E+05    .789E+05    .789E+05
16     .789E+05    .789E+05    .789E+05    .789E+05    .789E+05    .789E+05
17     .600E+00    .200E+00   0.          0.          0.          0.
18    0.          0.           .100E+00   0.           .100E+00   0.
19     .100E+00    .200E+00    .300E+00   0.          0.          0.
20    0.           .400E+00   0.          0.          0.          0.
21     .100E+00    .100E+00   0.          0.          0.          0.
22    0.          0.           .600E+00   0.           .200E+00   0.
23     .500E+00    .200E+00   0.          0.          0.          0.
24    0.          0.           .200E+00   0.           .100E+00   0.
25     .147E+09    .147E+09    .147E+09    .147E+09    .147E+04    .147E+09
26     .147E+09    .147E+09    .147E+09    .147E+09    .147E+09    .147E+09
27     .500E+12    .500E-06    .500E+00    .800E+03    .800E-07    .120E+14
28     .700E+00    .100E+00    .100E+00    .100E+00    .800E+00    .500E+06
29     .900E+00   0.          0.           .100E+00    .100E+01   0.
30     .155E+08    .100E-04    .120E+08    .120E+05    .200E+01    .920E+07
31     .100E+02    .100E+01    .100E-01    .100E+00    .408E-06    .800E+00
32     .500E+10    .100E-05    .100E+01    .250E+13    .360E-06    .370E+00
33     .600E+14    .200E-07    .210E+00    .500E+12    .127E+13    .177E+13
34     .904E+12   0.           .130E+13   0.          0.           .224E+05
35     .356E+04    .924E+02    .688E+03    .456E+03    .720E+04    .936E+04
36     .144E+04    .720E+04    .160E+00    .260E-01    .100E-02    .100E-02
37     .100E+01    .100E+01    .130E+01    .800E+00    .650E+00    .800E+00
38     .100E+01    .500E+00    .500E+00    .500E+00    .500E+00    .500E+00
39     .500E+00    .500E+00    .500E+00    .500E+00    .500E+00    .500E+00
40     .150E+00    .600E+00    .950E+00    .900E+00    .500E+00    .500E+00
41     .800E+00    .500E+00    .500E-01    .500E+00    .900E+00    .200E+01
42     .150E+01    .150E+01    .500E+02    .450E+00    .800E-01    .100E+01
43     .600E+00    .350E+00    .500E-01    .400E+03    .150E+03    .800E+02
44     .200E+00    .100E+01    .100E+01    .200E+00    .120E-05    .267E+05
45     .500E+01   0.          0.          0.          0.          0.
   0.500   0.300   0.100   0.050   0.050
49    0.          0.          0.          0.          0.          0.
```

Table D-3. INPUT DATA FOR LAKE MICHIGAN (KEYED TO TABLE D-1)

```
 1    .790E+02   .790E+02   .790E+02   .790E+02   .790E+02   .790E+02
 2    .790E+02   .790E+02   .790E+02   .790E+02   .790E+02   .790E+02
 3    .600E-01   .500E+00  0.          .943E+00  0.          .943E+00
 4   0.          .129E+10   .227E+09   .200E-04   .500E+00  0.
 5    .100E+02   .100E+02   .100E+02   .100E+02   .100E+02   .100E+02
 6    .100E+02   .100E+02   .100E+02   .100E+02   .100E+02   .100E+02
 7   0.         0.         0.         0.         0.         0.
 8   0.         0.         0.         0.         0.         0.
 9    .348E+05   .348E+05   .348E+05   .348E+05   .348E+05   .348E+05
10    .348E+05   .348E+05   .348E+05   .348E+05   .348E+05   .348E+05
11    .176E+07   .176E+07   .176E+07   .176E+07   .176E+07   .176E+07
12    .176E+07   .176E+07   .176E+07   .176E+07   .176E+07   .176E+07
13    .720E+05   .720E+05   .720E+05   .720E+05   .720E+05   .720E+05
14    .720E+05   .720E+05   .720E+05   .720E+05   .720E+05   .720E+05
15    .789E+05   .789E+05   .789E+05   .789E+05   .789E+05   .789E+05
16    .789E+05   .789E+05   .789E+05   .789E+05   .789E+05   .789E+05
17    .600E+00   .200E+00  0.         0.         0.         0.
18   0.         0.          .100E+00  0.          .100E+00  0.
19    .100E+00   .200E+00   .300E+00  0.         0.         0.
20   0.          .400E+00  0.         0.         0.         0.
21    .100E+00   .100E+00  0.         0.         0.         0.
22   0.         0.          .600E+00  0.          .200E+00  0.
23    .500E+00   .200E+00  0.         0.         0.         0.
24   0.         0.          .200E+00  0.          .100E+00  0.
25    .147E+09   .147E+09   .147E+09   .147E+09   .147E+09   .147E+09
26    .147E+09   .147E+09   .147E+09   .147E+09   .147E+09   .147E+09
27    .500E+13   .500E-06   .500E+00   .500E+03   .800E-07   .322E+15
28    .700E+00   .100E+00   .100E+00   .100E+00   .800E+00   .360E+07
29    .900E+00  0.         0.          .100E+00   .100E+01  0.
30    .155E+08   .710E-05   .120E+08   .120E+05  0.          .920E+07
31   0.         0.          .100E-01   .100E+00   .408E-06   .800E+00
32    .360E+10   .100E-05  0.          .170E+14   .360E-06   .370E+00
33    .661E+15   .200E-07  0.          .640E+14   .578E+15   .578E+15
34   0.         0.          .129E+15  0.         0.          .224E+05
35    .356E+08   .924E+02   .880E+03   .456E+03   .720E+04   .936E+04
36    .144E+05   .720E+04   .160E+00   .260E-01   .100E-02   .100E-02
37    .100E+01   .100E+01   .100E+01   .800E+00   .650E+00   .800E+00
38    .100E+01   .500E+00   .500E+00   .500E+00   .500E+00   .500E+00
39    .500E+00   .500E+00   .500E+00   .500E+00   .500E+00   .500E+00
40    .150E+00   .300E+00   .950E+00   .900E+00  0.          .500E+00
41    .800E+00  0.          .500E-01  0.          .900E+00   .200E+01
42    .150E+01   .150E+01   .100E+03   .450E+00   .800E-01   .500E+00
43    .800E+00   .200E+00  0.          .400E+03   .150E+03   .800E+02
44    .200E+00   .100E+01   .100E+01   .100E+01   .120E-05   .267E+05
45    .110E+02  0.         0.         0.         0.         0.
   0.640   0.143   0.090   0.035   0.031   0.013   0.013   0.011   0.010   0.009
   0.005
49   0.         0.         0.         0.         0.         0.
```

Table D-4. INPUT DATA FOR LAKE ERIE (KEYED TO TABLE D-1)

```
  1     .860E+02     .860E+02     .860E+02     .860E+02     .860E+02     .860E+02
  2     .860E+02     .860E+02     .860E+02     .860E+02     .860E+02     .860E+02
  3     .600E-01     .500E+00    0.            .943E+00    0.            .943E+00
  4    0.            .120E+10     .227E+09     .200E-04     .500E+00    0.
  5     .100E+02     .100E+02     .100E+02     .100E+02     .100E+02     .100E+02
  6     .100E+02     .100E+02     .100E+02     .100E+02     .100E+02     .100E+02
  7     .780E+09     .780E+09     .780E+09     .780E+09     .780E+09     .780E+09
  8     .780E+09     .780E+09     .780E+09     .780E+09     .780E+09     .780E+09
  9     .348E+05     .348E+05     .348E+05     .348E+05     .348E+05     .348E+05
 10     .348E+05     .348E+05     .348E+05     .348E+05     .348E+05     .348E+05
 11     .176E+07     .176E+07     .176E+07     .176E+07     .176E+07     .176E+07
 12     .176E+07     .176E+07     .176E+07     .176E+07     .176E+07     .176E+07
 13     .720E+05     .720E+05     .720E+05     .720E+05     .720E+05     .720E+05
 14     .720E+05     .720E+05     .720E+05     .720E+05     .720E+05     .720E+05
 15     .789E+05     .789E+05     .789E+05     .789E+05     .789E+05     .789E+05
 16     .789E+05     .789E+05     .789E+05     .789E+05     .789E+05     .789E+05
 17     .600E+00     .200E+00    0.           0.           0.           0.
 18    0.           0.            .100E+00    0.            .100E+00    0.
 19     .100E+00     .200E+00     .300E+00    0.           0.           0.
 20    0.            .400E+00    0.           0.           0.           0.
 21     .100E+00     .100E+00    0.           0.           0.           0.
 22    0.           0.            .600E+00    0.            .200E+00    0.
 23     .500E+00     .200E+00    0.           0.           0.           0.
 24    0.           0.            .200E+00    0.            .100E+00    0.
 25     .147E+09     .147E+09     .147E+09     .147E+09     .147E+09     .147E+09
 26     .147E+09     .147E+09     .147E+09     .147E+09     .147E+09     .147E+09
 27     .500E+12     .500E-05     .500E+00     .500E+03     .800E-07     .622E+14
 28     .700E+00     .100E+00     .100E+00     .100E+00     .820E+00     .125E+08
 29     .900E+00    0.           0.            .100E+00     .100E+01    0.
 30     .155E+09     .710E-05     .120E+08     .120E+05    0.            .920E+07
 31     .100E+02     .100E+01     .100E-01     .100E+00     .408E-06     .800E+00
 32     .125E+11     .100E-05     .100E+01     .304E+14     .360E-06     .370E+00
 33     .400E+15     .200E-07     .210E+00     .320E+14     .257E+15     .257E+15
 34    0.           0.            .639E+14     .167E+15     .198E-04     .224E+05
 35     .356E+04     .924E+02     .888E+03     .456E+03     .720E+04     .936E+04
 36     .144E+05     .720E+04     .160E+00     .260E-01     .100E-02     .100E-02
 37     .100E+01     .100E+01     .100E+01     .500E+00     .650E+00     .800E+00
 38     .100E+01     .500E+00     .500E+00     .500E+00     .500E+00     .500E+00
 39     .500E+00     .500E+00     .500E+00     .500E+00     .500E+00     .500E+00
 40     .150E+00     .600E+00     .950E+00     .900E+00     .500E+00     .500E+00
 41     .800E+00     .500E+00     .500E-01     .500E+00     .900E+00     .200E+01
 42     .150E+01     .150E+01     .100E+03     .450E+00     .800E-01     .500E+00
 43     .800E+00     .200E+00    0.            .400E+03     .150E+03     .800E+02
 44     .200E+00     .100E+01     .100E+01     .100E+01     .120E-05     .267E+05
 45     .110E+02    0.           0.           0.           0.           0.
    0.640    0.183    0.090    0.035    0.031    0.013    0.013    0.011    0.010    0.009
    0.005
 49    0.           0.           0.           0.           0.           0.
```

Table D-5. HYPOTHETICAL LAKE: PHOSPHORUS OUTPUT FROM THE MASS FLOW MODEL FOR UNCONTROLLED CONDITIONS AND FOR THE MAXIMUM APPLIED CONTROL STRATEGIES--SHOWING 99% PHOSPHORUS REMOVAL IN WASTE TREATMENT

PARAMETER YEAR 12	AMT (#/YR)	P TOTAL	P EFF	P AEFF	ACCUMULATED	TR PROC	COST
ORGANO PHOS PEST	538560.00	0.0002	0.0002		6462720.00		
STRIP MINE + TAILING	6300000.00	0.0020	0.0022	0.0060	75600000.00		
FERT RUNOFF(SLOPE=719.85)	1826074829.72	0.5706	0.6305		22780714029.28		
EROSION RATE	0.180						
ORG PHOSPHORUS	301560005.38	0.0942	0.1041		3618720064.52		
INORG PHOSPHORUS	1510114824.34	0.4719	0.5214		18997193964.72		
DRAIN PHOSPHORUS	14400000.00	0.0045	0.0050	0.0130	172800000.00		
IRR RETURN FLOW P	15600.00	0.0000	0.0000	0.0000	187200.00		
SOLID WASTE OUT	166666.67	0.0001	0.0001	0.0002	2000000.00		
NAT DEV RUNOFF	53588333.33	0.0167	0.0185	0.0513	643060000.01		
NATURAL RUNOFF	50000000.00	0.0156	0.0173		600000000.00		
DEVELOP RUNOFF	833333.33	0.0003	0.0003		10000000.00		
MAN. FOR. RUNOFF	1130000.00	0.0004	0.0004		13560000.00		
GRAZING RUNOFF	1625000.00	0.0005	0.0006		19500000.00		
RAINFALL	7080000.00	0.0022	0.0026	0.0068	84960000.00		
RIVER	0.00	0.0000	0.0000	0.0000	0.00		
DOM DIRECT DISCHARGE	0.00	0.0000	0.0000		0.00		
DOM DET DIRECT DISCH	0.00	0.0000	0.0000		0.00		
SEWERED DOMESTIC	318240000.00	0.0994			3818880000.00		
SEW DOM. DET P	333158400.00	0.1041			3997900800.00		
URBAN RUNOFF	16650000.00	0.0052			199800000.00		
IND DETER OUT	116202240.00	0.0363			1394426880.00		
MISC P OUT	77500000.00	0.0242			930000000.00		
WATER SOFTENING	46000000.00	0.0144			552000000.00		
METAL FIN OUT	12000000.00	0.0037			144000000.00		
FOOD WASTE OUT	1470000.00	0.0000			17640000.00		
MINING P OUT	24000.00	0.0000			288000.00		
MUN TREAT INFLUENT	785943520.00	0.2456			1628052000.00		
IND DET + OTHER IND	251873240.00	0.0787			3022478880.00		
COW MANURE OUT	123888000.00	0.0387			1486656000.00		
CHICK MANURE OUT	162624000.00	0.0508			1951488000.00		
PIG MANURE OUT	63936000.00	0.0200			767232000.00		
SHEEP MANURE OUT	35978400.00	0.0112			431740800.00		
IN-PLANT TRT METALS	2400000.00						
IN-PLANT TRT FOODS	147000.00					COAG	19820.75
UNTREATED TOTAL	3200062029.72				39276560429.28	NO TRT	0.00
COW AFTER TREAT	26919903.60		0.0093	0.0129	323038843.20		
CHICK AFTER TREAT	40725115.20		0.0141	0.0195	488701382.40		
PIG AFTER TREAT	5357836.80		0.0018	0.0026	64294041.60		
SHEEP AFTER TREAT	7033327.47		0.0024	0.0034	84399929.64		
UNSEWER DOM.	16650000.00		0.0057	0.0159	199800000.00		
UNSEWER IND.	119851120.00		0.0414	0.1148	1438213440.00		
UNTREATED METALS	0.00		0.0000	0.0000	0.00		
UNTREATED FOODS	0.00		0.0000	0.0000	0.00		
TREAT PLANT EFF	785943520.00		0.2714	0.7528	9431322240.00		0.00
TREAT P MINING EFF	4800.00		0.0000	0.0000	57600.00	REV OS	112.79
UNTREATED MINING	0.00		0.0000	0.0000	0.00		
TREATED TOTAL	2896265612.78	0.9051			35631003426.00		
AVAIL TREATED TOTAL	1044001131.52	0.3262	0.3605		12528013578.24		
DOM SEPTIC TANK	79560000.00				954720000.00		
DET SEPTIC TANK	83289600.00				999475200.00		
EUTROPHICATION (EFF)	1778.0048	1163.0673	592.9363	456.1048	296.4401	228.0524	182.4419
EUTROPHICATION (AEFF)	641.1975	419.2445	213.7325	164.4096	106.8663	82.2048	65.7639

Table D-5 (Con't)

PARAMETER YEAR 12	AMT (G/TR)	P TOTAL	P EFF	P AEFF	ACCUMULATED	TR PROC	COST
ORGANO PHOS PEST	0.00	0.0000	0.0000		0.00		
STRIP MINE + TAILING	0.00	0.0000	0.0000	0.0000	0.00		
FERT RUNOFF(SLOPE=597.07)	145909411.43	0.1424	0.6335		1956667898.59		
EROSION RATE	0.017						
ORG PHOSPHORUS	28267221.76	0.0276	0.1228		339446661.12		
INORG PHOSPHORUS	117622190.07	0.1140	0.5107		1617421237.48		
DRAIN PHOSPHORUS	0.00	0.0000	0.0000	0.0000	0.00		
IRR RETURN FLOW P	0.00	0.0000	0.0000	0.0000	0.00		
SOLID WASTE OUT	0.00	0.0000	0.0000	0.0000	0.00		
NAT DEV RUNOFF	53580333.33	0.0523	0.2327	0.6798	643060000.01		
NATURAL RUNOFF	50000000.00	0.0488	0.2171		600000000.00		
DEVELOP RUNOFF	833333.33	0.0008	0.0036		10000000.00		
MAN. FOR. RUNOFF	1130000.00	0.0011	0.0049		13560000.00		
GRAZING RUNOFF	1625000.00	0.0016	0.0071		19500000.00		
RAINFALL	7080000.00	0.0069	0.0307	0.0898	84960000.00		
RIVER	0.00	0.0000	0.0000	0.0000	0.00		
DOM DIRECT DISCHARGE	0.00	0.0000	0.0000		0.00		
DOM DET DIRECT DISCH	0.00	0.0000	0.0000		0.00		
SEWERED DOMESTIC	318240000.00	0.3107			3818880000.00		
SEW DOM. DET P	13766400.00	0.0134			165196800.00		
URBAN RUNOFF	8325000.00	0.0081			99900000.00		
IND DETER OUT	1290240.00	0.0013			15482880.00		
MISC P OUT	77500000.00	0.0757			930000000.00		
WATER SOFTENING	0.00	0.0000			0.00		
METAL FIN OUT	12000000.00	0.0117			144000000.00		
FOOD WASTE OUT	147000.00	0.0001			1764000.00		
MINING P OUT	24000.00	0.0000			288000.00		
MUN TREAT INFLUENT	425490640.00	0.4154			1076052000.00		
IND DET + OTHER IND	90961240.00	0.0888			1091534880.00		
COW MANURE OUT	123888000.00	0.1209			1486656000.00		
CHICK MANURE OUT	162624000.00	0.1584			1951488000.00		
PIG MANURE OUT	63936000.00	0.0624			767232000.00		
SHEEP MANURE OUT	35978400.00	0.0351			431740800.00		
IN-PLANT TRT METALS	2400000.00					COAG	15828.75
IN-PLANT TRT FOODS	147000.00					NO TRT	0.00
UNTREATED TOTAL	1024296785.17				12497516378.48		
COW AFTER TREAT	3577266.00		0.0155	0.0227	42927192.00		
CHICK AFTER TREAT	3878582.40		0.0168	0.0246	46542988.80		
PIG AFTER TREAT	2589408.00		0.0112	0.0164	31072896.00		
SHEEP AFTER TREAT	1108584.45		0.0048	0.0070	13303013.40		
UNSEWER DOM.	8325000.00		0.0361	0.1056	99900000.00		
UNSEWER IND.	0.00		0.0000	0.0000	0.00		
UNTREATED METALS	0.00		0.0000	0.0000	0.00		
UNTREATED FOODS	0.00		0.0000	0.0000	0.00		
TREAT PLANT EFF	4254906.40		0.0185	0.0540	51058876.40		2747566.23
TREAT P MINING EFF	4800.00		0.0000	0.0001	57600.00	REV OS	112.79
UNTREATED MINING	0.00		0.0000	0.0000	0.00		
TREATED TOTAL	230316292.42	0.2249			2969750465.61		
AVAIL TREATED TOTAL	78829960.16	0.0770	0.3423		945959521.90		
DOM SEPTIC TANK	79560000.00				954720000.00		
DET SEPTIC TANK	3441600.00				41299200.00		
EUTROPHICATION (EFF)	141.4541	92.4892	47.1514	36.2703	23.5757	18.1351	14.5081
EUTROPHICATION (AEFF)	48.4153	31.6561	16.1384	12.4142	8.0692	6.2071	4.9657

Table D-5 (Con't)

PLANT	FLOW(L/YR)	INFLUENT(MG/L)	EFFLUENT(MG/L)	P REMOVAL(PERCENT)	COST	PROCESS
1	34980477999.9488	6.08	0.06	0.99	3346680.21	REV OS
2	20993100000.0000	6.08	0.06	0.99	2304738.05	REV OS
3	6997703000.0000	6.08	0.06	0.99	980967.79	REV OS
4	3498850000.0000	6.08	0.06	0.99	557590.11	REV OS
5	3498853000.0000	6.08	0.06	0.99	557590.11	REV OS
TOTAL	69976993999.8976				7747566.23	

Table D-6. LAKE MICHIGAN: PHOSPHORUS OUTPUT FROM THE MASS FLOW MODEL FOR UNCONTROLLED CONDITIONS AND FOR THE MAXIMUM APPLIED CONTROL STRATEGIES--SHOWING 99% PHOSPHORUS REMOVAL IN WASTE TREATMENT

PARAMETER YEAR 12	AMT (G/YR)	P TOTAL	P EFF	P AEFF	ACCUMULATED	TR PROC	COST
ORGANO PHOS PEST	14451360.00	.0004	0.0004		173416320.00		
STRIP MINE + TAILING	9875000.00	0.0002	0.0002	0.0009	118500000.00		
FERT RUNOFF(SLOPE=365.97)	20864412044.00	0.7163	0.7197		3779644036554.24		
EROSION RATE	0.171						
ORG PHOSPHORUS	7721618836.56	0.1911	0.1925		92661026040.32		
INORG PHOSPHORUS	20756193207.60	0.5136	0.5175		200666010517.12		
DRAIN PHOSPHORUS	386400000.00	0.0096	0.0096	0.0334	4636800000.00		
IRR RETURN FLOW P	0.00	0.0000	0.0003	0.0000	0.00		
SOLID WASTE OUT	216034.62	0.0000	0.0000	0.0000	2592415.38		
NAT DEV RUNOFF	1375824943.81	0.0340	0.0343	0.1189	16509899326.16		
NATURAL RUNOFF	927033932.58	0.0229	0.0231		11124407191.04		
DEVELOP RUNOFF	179516604.49	0.0044	0.0045		2154196853.97		
MAN. FOR. RUNOFF	0.00	0.0000	0.0000		0.00		
GRAZING RUNOFF	269274600.74	0.0067	0.0067		3231295208.97		
RAINFALL	3652960000.00	0.0904	0.0911	0.3156	43835520000.00		
RIVER	0.00	0.0000	0.0000	0.0000	0.00		
DOM DIRECT DISCHARGE	0.00	0.0000	0.0000		0.00		
DOM DET DIRECT DISCH	0.00	0.0000	0.0000		0.00		
SEWERED DOMESTIC	2291328000.00	0.0567			27495936000.00		
SEW DOM. DET P	2398740480.00	0.0594			28784885760.00		
URBAN RUNOFF	178887600.00	0.0044			2146651200.00		
IND OTHER OUT	594025850.04	0.0147			7128310210.48		
MISC P OUT	396180000.00	0.0098			4754160000.00		
WATER SOFTENING	235152000.00	0.0058			2821824000.02		
METAL FIN OUT	12000000.00	0.0003			144000000.00		
FOOD WASTE OUT	147000.00	0.0000			1764000.00		
MINING P OUT	0.00	0.0000			0.00		
MUN TREAT INFLUENT	5327337103.44	0.1318			77217480000.00		
IND DET + OTHER IND	1237504850.08	0.0306			14850058210.48		
COW MANURE OUT	123388000.00	0.0031			1480656000.00		
CHICK MANURE OUT	162624000.00	0.0040			1951488000.00		
PIG MANURE OUT	63936000.00	0.0016			767232000.00		
SHEEP MANURE OUT	35978400.00	0.0009			431740800.00		
IN-PLANT TRT METALS	2400000.00					COAG	15828.75
IN-PLANT TRT FOODS	147000.00					NO TRT	0.00
UNTREATED TOTAL	40410626713.36				516519212584.96		
COW AFTER TREAT	26985903.60		0.0007	0.0018	323830843.20		
CHICK AFTER TREAT	40725115.20		0.0010	0.0018	488701382.40		
PIG AFTER TREAT	5357836.80		0.0001	0.0002	64294041.60		
SHEEP AFTER TREAT	7033327.47		0.0002	0.0003	84399929.64		
UNSEWER DOM.	168154344.00		0.0042	0.0145	2017852128.00		
UNSEWER IND.	612678925.44		0.0153	0.0529	7352147105.28		
UNTREATED METALS	820800.00		0.0000	0.0001	9849600.00		
UNTREATED FOODS	16758.00		0.0000	0.0000	201096.00		
TREAT PLANT EFF	5327337103.45		0.1328	0.4603	63928045241.40		0.00
TREAT P MINING EFF	0.00		0.0000	0.0000	0.00	NO TRT	0.00
UNTREATED MINING	0.00		0.0000	0.0000	0.00		
TREATED TOTAL	40106849496.64	0.9925			512873885962.72		
AVAIL TREATED TOTAL	11574315001.04	0.2864	0.2886		138892020012.16		
DOM SEPTIC TANK	572832000.00				6873984000.00		
DET SEPTIC TANK	599685120.00				7196221440.00		
EUTROPHICATION (EFF)	54.1234	35.3084	18.0411	13.6776	9.0206	6.9389	5.5511
EUTROPHICATION (AEFF)	15.6193	10.2126	5.2084	4.0050	2.6032	2.0025	1.6020

Table D-6 (Con't)

PARAMETER YEAR 12	AMT (B/YR)	P TOTAL	P EFF	P AEFF	ACCUMULATED	TR PROC	COST
ORGANO PHOS PEST	0.00	0.0000	0.0000		0.00		
STRIP MINE + TAILING	0.00	0.0000	0.0000	0.0000	0.00		
FERT RUNOFF(SLOPE==385.97)	5598671388.37	0.4025	0.5708		73394865966.72		
EROSION RATE	0.034						
ORG PHOSPHORUS	1518060901.13	0.1091	0.1412		18216470813.52		
INORG PHOSPHORUS	4080592487.22	0.2934	0.3796		55177495153.26		
DRAIN PHOSPHORUS	0.00	0.0000	0.0000	0.0000	0.00		
IRR RETURN FLOW P	0.00	0.0000	0.0000	0.0000	0.00		
SOLID WASTE OUT	0.00	0.0000	0.0000	0.0000	0.00		
NAT DEV RUNOFF	1375828483.03	0.0989	0.1250	0.2673	10509899326.16		
NATURAL RUNOFF	927033937.58	0.0657	0.0962		11124467191.04		
DEVELOP RUNOFF	179516404.49	0.0129	0.0167		2154196353.97		
MAN. FOR. RUNOFF	0.00	0.0000	0.0000		0.00		
GRAZING RUNOFF	269274606.74	0.0194	0.0250		3231295280.47		
RAINFALL	3652960000.00	0.2625	0.3348	0.7048	43835520000.00		
RIVER	0.00	0.0000	0.0000	0.0000	0.00		
DOM DIRECT DISCHARGE	0.00	0.0000	0.0000		0.00		
DOM DET DIRECT DISCH	0.00	0.0000	0.0000		0.00		
SEWERED DOMESTIC	2291328000.00	0.1647			27495936000.00		
SEW DOM. DET P	99118080.00	0.0071			1189416960.00		
URBAN RUNOFF	89443800.00	0.0064			1073325600.00		
IND DETER OUT	6595706.88	0.0005			79148482.56		
MISC P OUT	396180000.00	0.0295			4754160000.00		
WATER SOFTENING	0.00	0.0000			0.00		
METAL FIN OUT	12000000.00	0.0009			144000000.00		
FOOD WASTE OUT	147000.00	0.0000			1764000.00		
MINING P OUT	0.00	0.0000			0.00		
MUN TREAT INFLUENT	2013282414.08	0.2323			4899924000.00		
IND DET + OTHER IND	414922708.88	0.0296			4979072402.52		
COW MANURE OUT	123888000.00	0.0089			1486656000.00		
CHICK MANURE OUT	162624000.00	0.0117			1951488000.00		
PIG MANURE OUT	63936000.00	0.0046			767232000.00		
SHEEP MANURE OUT	35978400.00	0.0026			431740800.00		
IN-PLANT TRT METALS	2400300.00					COAG	15820.75
IN-PLANT TRT FOODS	147000.00					NO TRT	0.00
UNTREATED TOTAL	13900645319.12				173115153137.28		
COW AFTER TREAT	3577266.00		0.0003	0.0003	42927192.00		
CHICK AFTER TREAT	3878582.40		0.0008	0.0004	46542988.80		
PIG AFTER TREAT	2589408.00		0.0002	0.0003	31072896.00		
SHEEP AFTER TREAT	1108584.45		0.0001	0.0001	13303013.40		
UNSEWER DOM.	84077172.00		0.0078	0.0163	1008926064.00		
UNSEWER IND.	0.00		0.0000	0.0000	0.00		
UNTREATED METALS	0.00		0.0000	0.0000	0.00		
UNTREATED FOODS	0.00		0.0000	0.0000	0.00		
TREAT PLANT EFF	28132820.15		0.0026	0.0055	337593841.78		85125838.56
TREAT P MINING EFF	0.00		0.0000	0.0000	0.00	NO TRT	0.00
UNTREATED MINING	0.00		0.0000	0.0000	0.00		
TREATED TOTAL	10750820169.12	0.7730			135220651336.96		
AVAIL TREATED TOTAL	5146571860.41	0.3700	0.4787		61758862324.48		
DOM SEPTIC TANK	572832000.00				6873984000.00		
DET SEPTIC TANK	24779520.00				297354240.00		
EUTROPHICATION (EFF)	14.5000	9.4880	4.8360	3.7200	2.4180	1.8600	1.4880
EUTROPHICATION (AEFF)	6.9452	4.5411	2.3151	1.7808	1.1575	0.8904	0.7123

Table D-6 (Con't)

PLANT	FLOW(L/YR)	INFLUENT(MG/L)	EFFLUENT(MG/L)	P REMOVAL(PERCENT)	COST	PROCESS
1	319573024990.0000	5.36	0.05	0.99	26419092.08	REV OS
2	79006419000.1024	5.36	0.05	0.99	5903015.49	REV OS
3	67232149000.2048	5.36	0.05	0.99	6175446.45	REV OS
4	18360035000.0000	5.36	0.05	0.99	2084430.36	REV OS
5	16240004900.0000	5.36	0.05	0.99	1900844.09	REV OS
6	6022423800.0000	5.36	0.05	0.99	961305.11	REV OS
7	6022423800.0000	5.36	0.05	0.99	961305.11	REV OS
8	5772617600.0000	5.36	0.05	0.99	439994.65	REV OS
9	5240016000.0000	5.36	0.05	0.99	777472.02	REV OS
10	4723214400.0000	5.36	0.05	0.99	713494.02	REV OS
11	2624000000.0000	5.36	0.05	0.99	419063.20	REV OS
TOTAL	524001399999.1000				45125436.56	

Reproduced from best available copy.

Table D-7. LAKE ERIE: PHOSPHORUS OUTPUT FROM THE MASS FLOW MODEL FOR UNCONTROLLED CONDITIONS AND FOR THE MAXIMUM APPLIED CONTROL STRATEGIES--SHOWING 99% PHOSPHORUS REMOVAL IN WASTE TREATMENT

```
PARAMETER       Y E A R 12        AMT (G/YR)     P TOTAL     P EFF      P AEFF      ACCUMULATED  TR PROC       COST

GROUND PHOS PEST                  2791536.00      0.0001    0.0001                  33498432.00
STRIP MINE + TAILING             10750000.00      0.0003    0.0003     0.0004      129000000.00
FERT RUNOFF(SLOPE=3.5.07)      5575672140.16      0.1688    0.1704               73010560229.12
   EROSION RATE                        0.171
   ORG PHOSPHORUS              1491605990.06      0.0452    0.0456               17899271986.40
   INORG PHOSPHORUS            4009426141.34      0.1214    0.1225               54215600242.56
   GRAIN PHOSPHORUS              74440000.00      0.0023    0.0023     0.0029      893280000.00
IRR RETURN FLOW P                   15600.00      0.0000    0.0000     0.0000         187200.00
SOLID WASTE OUT                    832082.48      0.0000    0.0000     0.0000        9984989.59
NAT VEG RUNOFF                  862635541.67      0.0261    0.0264     0.0238    10351626500.00
   NATURAL RUNOFF               616377333.33      0.0187    0.0188                7396527999.92
   DEVELOP RUNOFF                98613333.33      0.0030    0.0030                1183360000.00
   RAN. FOR. RUNOFF                     0.00      0.0000    0.0000                         0.00
   GRAZING RUNOFF               147438875.00      0.0045    0.0045                1772266500.00
RAINFALL                       1768160000.02      0.0535    0.0940     0.0893    21217920000.18
RIVER                          3306600000.00      0.1011    0.1001     0.1296    39679200000.00
DOM DIRECT DISCHARGE                    0.00      0.0000    0.0000                         0.00
DOM DET DIRECT DISCH                    0.00      0.0000    0.0000                         0.00
SEWERED DOMESTIC               7956000000.00      0.2409                           95472000000.00
SEW DOM. DET P                 8537184000.00      0.2585                          102446208000.00
URBAN RUNOFF                    348234080.00      0.0105                            4178808960.00
IND OTHER OUT                  2062589760.00      0.0625                           24751077120.00
MISC P OUT                     1375625000.00      0.0417                           16507500000.00
WATER SOFTENING                8165000000.00      0.0247                           97980000000.00
METAL FIN OUT                    12000000.00      0.0004                             144000000.00
FOOD WASTE OUT                     147000.00      0.0000                               1764000.00
MINING P OUT                            0.00      0.0000                                     0.00
MUN TREAT INFLUENT            18655292100.72      0.5649                           26451264000.00
IND DET + OTHER IND            4266861760.00      0.1292                           51202341120.00
COW MANURE OUT                  123048000.00      0.0038                            1476576000.00
CHICK MANURE OUT                162624000.00      0.0049                            1951488000.00
PIG MANURE OUT                   63936000.00      0.0019                             767232000.00
SHEEP MANURE OUT                 35978400.00      0.0011                             431740800.00
IN-PLANT TRT METALS               2400000.00                                                      COAG       15828.75
IN-PLANT TRT FOODS                 147000.00                                                      NO TRT         0.00
UNTREATED TOTAL               33027167240.72                                      402366509834.24

COW AFTER TREAT                  26965903.60                0.0008     0.0005      323630843.20
CHICK AFTER TREAT                40725115.20                0.0012     0.0008      488701382.40
PIG AFTER TREAT                   5357670.00                0.0002     0.0001       64292041.00
SHEEP AFTER TREAT                 7033327.47                0.0002     0.0001       84399929.64
UNSEWER DOM.                    327343795.20                0.0100     0.0120     3928125542.40
UNSEWER IND.                   2127357380.00                0.0650     0.0034    25528288560.00
UNTREATED METALS                  820800.00                 0.0000     0.0000        9849600.00
UNTREATED FOODS                    16750.00                 0.0000     0.0000         201000.00
TREAT PLANT EFF               18655292100.88                0.5702     0.7318   223863505203.84                 0.00
TREAT P MINING EFF                      0.00                0.0000     0.0000              0.00  NO TRT         0.00
UNTREATED MINING                        0.00                0.0000     0.0000              0.00
TREATED TOTAL                 32719396728.04      0.9904                          398723183232.00

AVAIL TREATED TOTAL           25521215958.24      0.7729    0.7808                306254591473.28

DOM SEPTIC TANK                1989000000.00                                       23868000000.00
DET SEPTIC TANK                1874016000.00                                       22488192000.00

EUTROPHICATION (EFF)         99.3818      66.9275       33.1043       25.4618       16.5502       12.7389       10.1867
EUTROPHICATION (AEFF)        77.4574      50.6452       25.0191       19.8499       12.9096        9.9204        7.9443
```

Table D-7 (Con't)

PARAMETER Y E A R 12	ANT (G/YR)	P TOTAL	P EFF	P AEFF	ACCUMULATED	TR PROC	COST
ORGANO PHOS PEST	0.00	0.0000	0.0000		0.00		
STRIP MINE + TAILING	0.00	0.0000	0.0000	0.0000	0.00		
FERT RUNOFF(SLOPE=305.97)	1081402695.58	0.0625	0.1403		14177517567.16		
EROSION RATE	0.034						
ORG PHOSPHORUS	293244198.91	0.0170	0.0402		3518930386.91		
INORG PHOSPHORUS	788238206.66	0.0456	0.1001		10658587200.40		
DRAIN PHOSPHORUS	0.00	0.0000	0.0000	0.0000	0.00		
IRR RETURN FLOW P	0.00	0.0000	0.0000	0.0000	0.00		
SOLID WASTE OUT	0.00	0.0000	0.0030	0.0000	0.00		
NAT DEV RUNOFF	862635541.67	0.0499	0.1193	0.1070	10351626500.00		
NATURAL RUNOFF	616333333.33	0.0356	0.0845		7395999999.92		
DEVELOP RUNOFF	98613333.33	0.0057	0.0135		1183360000.00		
MAN. FOR. RUNOFF	0.00	0.0000	0.0000		0.00		
GRAZING RUNOFF	147688875.00	0.0085	0.0233		1772266500.00		
RAINFALL	1768160000.02	0.1022	0.2425	0.3065	21217920000.16		
RIVER	3306600000.00	0.1915	0.1911	0.2266	39679200000.00		
DOM DIRECT DISCHARGE	0.00	0.0000	0.0000		0.00		
DOM DET DIRECT DISCH	0.00	0.0000	0.0000		0.00		
SEWERED DOMESTIC	7956000000.00	0.4599			95472000000.00		
SEW DOM. DET P	352764000.00	0.0204			4233168000.02		
URBAN RUNOFF	174119040.00	0.0101			2089428480.00		
IND OTHER OUT	22901760.00	0.0013			274821120.00		
MISC P OUT	1375625000.00	0.0795			16507500000.00		
WATER SOFTENING	0.00	0.0000			0.00		
METAL FIN OUT	12000000.00	0.0007			144000000.00		
FOOD WASTE OUT	147000.00	0.0000			1764000.00		
MINING P OUT	0.00	0.0000			0.00		
RUN TREAT INFLUENT	9732431302.40	0.5628			116653264000.00		
IND DET + OTHER IND	1410673760.00	0.0815			16928085120.00		
COW MANURE OUT	123888000.00	0.0072			1486656000.00		
CHICK MANURE OUT	162624000.00	0.0094			1951488000.00		
PIG MANURE OUT	63936000.00	0.0037			767232000.00		
SHEEP MANURE OUT	35978400.00	0.0021			431740800.00		
IN-PLANT TRT METALS	2400000.00					COAG	15820.75
IN-PLANT TRT FOODS	147000.00					NO TRT	0.00
UNTREATED TOTAL	17290861227.28				208786062460.32		
COW AFTER TREAT	3577260.00		0.0005	0.0004	42927120.00		
CHICK AFTER TREAT	3878582.40		0.0005	0.0004	46542988.80		
PIG AFTER TREAT	2589408.00		0.0004	0.0003	31072896.00		
SHEEP AFTER TREAT	1108584.45		0.0002	0.0001	13303013.40		
UNSEWER DOM.	163671897.60		0.0224	0.0360	1964062771.17		
UNSEWER IND.	0.00		0.0000	0.0000	0.00		
UNTREATED METALS	0.00		0.0000	0.0000	0.00		
UNTREATED FOODS	0.00		0.0000	0.0000	0.00		
TREAT PLANT EFF	97324319.02		0.0133	0.0214	1167891828.24		143497630.72
TREAT P MINING EFF	0.00		0.0000	0.0000	0.00	NO TRT	0.00
UNTREATED MINING	0.00		0.0000	0.0000	0.00		
TREATED TOTAL	7291028086.72	0.4215			86692064770.24		
AVAIL TREATED TOTAL	4550668678.72	0.2631	0.6241		54608024145.28		
DOM SEPTIC TANK	1989000000.00				23868000000.00		
DET SEPTIC TANK	77436000.00				929232000.00		
EUTROPHICATION (EFF)	22.1284	14.4686	7.3761	5.6740	3.6881	2.8370	2.2496
EUTROPHICATION (AEFF)	13.8114	9.0305	4.6038	3.5414	2.3019	1.7707	1.4166

Reproduced from best available copy.

Table D-7 (Con't)

PLANT	FLOW(L/YR)	INFLUENT(MG/L)	EFFLUENT(MG/L)	P REMOVAL(PERCENT)	COST	PROCESS
1	1134056673201.6304	5.49	0.05	0.99	89265605.01	REV OS
2	253564995239.4496	5.49	0.05	0.99	19945301.67	REV OS
3	1595949501199.9744	5.49	0.05	0.99	12552987.07	REV OS
4	62062561000.2176	5.49	0.05	0.99	4952123.66	REV OS
5	59969717000.0000	5.49	0.05	0.99	4570759.24	REV OS
6	23051816039.9872	5.49	0.05	0.99	2471084.13	REV OS
7	23051816039.9872	5.49	0.05	0.99	2471084.13	REV OS
8	19505303400.0128	5.49	0.05	0.99	2141079.37	REV OS
9	17732160000.0256	5.49	0.05	0.99	2079563.39	REV OS
10	15950953119.9872	5.49	0.05	0.99	1073133.08	REV OS
11	6000008399.9872	5.49	0.05	0.99	1100020.95	REV OS
TOTAL	1773216000001.5360				143097630.72	

APPENDIX E

MARGARINE EXCISE TAXES

The tables in this appendix were developed to show the impact of an excise tax on the consumption of butter and margarine. A look at Table E-1 shows that margarine consumption has risen while butter consumption has steadily fallen. Quite clearly the two products are substitutes. In Utah, where margarine was heavily taxed relative to many other parts of the country, consumption was less than for the country as a whole. The federal excise tax was repealed in 1959, leading to a considerable shift in 1961. The restriction on color was also repealed.

A simple equation was next developed to look at the effect on margarine consumption of a change in prices and income. This was done for the United States in Table E-2 and for the State of Utah in Table E-3. The tables perhaps show that price is a more important variable than income. The one major surprise, however, and the reason these tables are included are the generally positive signs attached to income. Many people grew up with the idea that margarine was an inferior product, that people only ate it because they couldn't afford butter. If this were true, then as income rose the consumption of margarine should have fallen. These tables show that for the most part, higher incomes have not meant less consumption of margarine at all. It might very well be true that high phosphate detergent is popular not because of its supposed superior cleaning power relative to soap, but mostly because it is cheaper.

The revenue from Utah's 10¢-a-pound excise tax is now over one million dollars and will be repealed as of July 1, 1973. The big argument for retaining it was because of its revenue potential. Reapportionment has given greater representation to the cities and the repeal passed easily with only the representatives of counties with large dairy interests voting against it.

Table E-1. PER CAPITA MARGARINE AND BUTTER CONSUMPTION (1927-1970)

Year	Butter, U.S.	Margarine, U.S.	Margarine, Utah
	Pounds	Pounds	Pounds
1922		1.72	
1923		1.85	
1924		2.08	
1925	17.7	1.84	
1926	17.5	2.09	
1927	17.5	2.97	
1928	17.2	2.42	
1929	17.4	2.70	
1930	17.3	2.81	
1931	18.0	2.23	.870
1932	18.1	1.71	.300
1933	17.8	1.72	.021
1934	18.2	1.91	.030
1935	17.1	2.76	1.070
1936	16.4	2.89	1.100
1937	16.3	3.01	1.820
1938	16.4	3.19	1.760
1939	17.3	2.54	.690
1940	16.9	2.29	.910
1941	15.9	2.59	1.750
1942	15.6	2.70	3.370
1943	11.7	3.38	3.280
1944	11.8	3.82	3.360
1945	10.8	4.35	3.490
1946	10.4	3.61	3.210
1947	11.1	4.15	4.860
1948	9.9	5.93	8.600
1949	10.4	5.76	8.340
1950	10.6	5.53	6.140
1951	9.5	6.39	9.460

Table E-1 (Cont'd)

Year	Butter, U.S.	Margarine, U.S.	Margarine, Utah
	Pounds	Pounds	Pounds
1952	8.6	7.95	9.200
1953	8.5	8.05	9.890
1954	8.9	8.50	8.910
1955	9.0	8.20	8.480
1956	8.7	8.20	8.090
1957	8.3	8.60	8.010
1958	8.3	9.00	8.310
1959	7.9	9.20	8.750
1960	7.5	9.40	7.130
1961	7.4	9.40	8.580
1962	7.3	9.30	8.000
1963	6.9	9.60	8.770
1964	6.8	9.70	7.610
1965	6.4	9.90	8.050
1966	5.7	10.50	8.410
1967	5.5	10.50	8.350
1968	5.6	10.80	8.360
1969	5.4	10.80	10.240
1970	5.3	11.00	10.000

Table E-2. UNITED STATES MARGARINE CONSUMPTION

Dependent Variable	Independent Variables						
Margarine/Pop	Intercept	Price of Margarine	Price of Butter	Butter/Pop	Income U.S.	df	R^2
(1920-70-UNA0	6.936	-0.096 (5.653)	0.053 (4.293	-0.053 (20.778)	0.001 (16.937)	46	.96
	.112	-0.168 (14.373)	0.117 (21.249)		0.002 (34.784)	47	.95
(1920-70-A)	14.763	-0.022 (0.2814)	-0.048 (6.064)	-0.503 (30.633)	0.001 (1.574)	46	.95
(1930-70-UNA)	6.967	-0.108 (3.341)	0.057 (2.667)	-0.310 (7.472)	0.001 (10.595)	36	.95
	.117	-0.139 (4.908)	0.109 (12.045)		0.002 (26.991)	37	.94
(1930-70-A)	25.871	-0.013 (0.129)	-0.107 (26.214)	-0.780 (60.792)	-0.001 (2.232)	36	.96

Table E-2 (Cont'd)

Dependent Variable	Independent Variables					df	R^2
Margarine/Pop	Intercept	Price of Margarine	Price of Butter	Butter/Pop	Income U.S.		
			Price Difference Variable				
(1920-70-UNA)	-0.529	0.083 (16.265)			0.002 (55.387)	48	.94
(1930-70-UNA)	-0.161	0.089 (18.563)			0.002 (42.511)	38	.94
(1920-70-A)	0.741	-0.637 (6.868)			0.005 (375.110)	48	.92
(1930-70-A)	-2.548	-0.016 (0.093)			0.006 (116.234)	38	.76
(1930-70-WWII-UNA)	0.099	0.833 (15.140)			0.002 (40.351)	33	.94
(1950-70-UNA)	5.769	-0.023 (0.326)			0.002 (41.842)	18	.82

Table E-3. UTAH MARGARINE CONSUMPTION PER CAPITA

Dependent Variable	Independent Variables					df	R^2
Margarine/Pop	Intercept	Price of Margarine	Price of Butter	Butter/Pop	Income Utah		
(1920-70-UNA)	7.892	-0.142	0.131	-0.517	-0.001	46	.92
		(4.929)	(10.706)	(18.964)	(1.663)		
	-3.204	-0.218	0.207		0.001	47	.89
		(9.079)	(23.573)		(1.766)		
(1920-70-A)	15.251	0.051	0.005	-0.878	(-0.001	46	.91
		(0.697)	(0.033)	(36.517)	(0.866)		
(1930-70-UNA)	0.905	-0.066	0.140	-0.217	0.000	36	.92
		(0.581)	(7.702)	(1.410)	(0.002)		
	-3.854	-0.077	0.168		0.001	37	.91
		(0.801)	(14.209)		(1.094)		
(1930-70-A)	20.229	0.057	-0.007	-1.039	-0.003	36	.89
		(0.748)	(0.036)	(34.576)	(3.049)		

Table E-3 (Cont'd)

Dependent Variable	Independent Variable					df	R^2
Margarine/Pop	Intercept	Price of Margarine	Price of Butter	Butter/Pop	Income Utah		
			Price Difference Variable				
(1920-70-UNA)	-3.337	0.199 (36.530)			0.001 (2.867)	48	.89
(1930-70-UNA)	-3.031	0.230 (52.449)			0.000 (0.023)	38	.90
(1920-70-A)	-1.806	-0.033 (0.701)			0.006 (172.400)	48	.82

APPENDIX F

SUMMARY OF MODEL OUTPUT FOR COST EFFECTIVENESS ANALYSIS

Table F-1

Hypothetical STRATEGY: All MGMNT; FAC2 = 0.5

System Total: 1.66×10^9

Strategy Total: 9.14×10^8

% EFF: 45

	EFF P			A EFF P		CONCENTR.			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
0	85	5.41×10^8	67	81	5.14×10^8	6.82	6.82	0	
50	55	3.48×10^8	79	51	3.21×10^8	6.82	3.41	2.67×10^5	C
60	49	3.10×10^8	81	45	2.83×10^8	6.82	2.73	2.67×10^5	C
70	43	2.71×10^8	84	38	2.44×10^8	6.82	2.05	2.67×10^5	C
80	37	2.32×10^8	86	32	2.06×10^8	6.82	1.36	3.72×10^5	C
84	34	2.17×10^8	87	30	1.90×10^8	6.82	1.09	4.49×10^5	C
86	33	2.09×10^8	87	29	1.82×10^8	6.82	0.95	2.55×10^6	I
88	32	2.01×10^8	88	28	1.75×10^8	6.82	0.82	2.55×10^6	I
90	31	1.94×10^8	88	26	1.67×10^8	6.82	0.68	2.55×10^6	I
92	--	--	--	--	--	--	--	--	-
93	--	--	--	--	--	--	--	--	-
94	28	1.78×10^8	89	24	1.52×10^8	6.82	0.41	6.38×10^6	R
95	--	--	--	--	--	--	--	--	
96	27	1.71×10^8	90	23	1.44×10^8	6.82	0.27	6.47×10^6	R
97	--	--	--	--	--	--	--	--	
98	26	1.63×10^8	90	21	1.36×10^8	6.82	0.14	6.56×10^6	R
99	25	1.59×10^8	90	21	1.32×10^8	6.82	0.07	6.60×10^6	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-1 (Con't)

Hypothetical STRATEGY: P = 0.10

System Total: 1.66×10^9

Strategy Total: 1.42×10^9

% EFF: 14

TREAT % removal	EFF Eut	EFF g/yr	System % removal	A EFF P Eut	A EFF P g/yr	CONCENTR. Before	CONCENTR. After	COST $/yr	Treatment Process*
0	175	1.11×10^9	33	164	1.04×10^9	12.42	12.42	--	
50	113	7.19×10^8	57	103	6.41×10^8	12.42	6.21	5.18×10^5	C
60	101	6.41×10^8	[illegible]	90.1	5.72×10^8	12.42	4.97	5.18×10^5	C
70	89	5.62×10^8	[illegible]	78	4.94×10^8	12.42	3.72	5.18×10^5	C
80	76	4.83×10^8	71	65	4.15×10^8	12.42	2.48	7.28×10^5	C
84	71	4.52×10^8	73	60	3.84×10^8	12.42	1.99	8.79×10^5	C
86	69	4.36×10^8	[illegible]	58	3.68×10^8	--	1.74	9.56×10^5	C
88	66	4.21×10^8	75	55	3.52×10^8	12.42	1.49	1.03×10^6	C
90	64	4.05×10^8	76	53	3.37×10^8	--	1.24	1.11×10^6	C
92	--	--		51	3.21×10^8	12.42	0.99	3.06×10^6	I
93	--	--	-	49	3.13×10^8	12.42	0.87	3.09×10^6	I
94	59	3.73×10^8	78	48	3.05×10^8	12.42	0.74	3.11×10^6	I
95		--	--	47	2.97×10^8	12.42	0.62	3.14×10^6	I
96	56	3.58×10^8	78	46	2.89×10^8	12.42	0.50	7.04×10^6	R
97	--	--		44	2.82×10^8	12.42	0.37	7.09×10^6	R
98	54	3.42×10^8	79	43	2.74×10^8	12.42	0.25	7.14×10^6	R
99	53	3.34×10^8	80	42	2.66×10^8	12.42	0.12	7.18×10^6	R

C - Coagulation
I - Ion Exchange
R Reverse Osmosis

Table F-1 (Con't)

Hypothetical STRATEGY: INDUST DET

System Total: $1,66 \times 10^9$

Strategy Total: $1,55 \times 10^9$

% EFF: 6,6

	EFF P			A EFF P		CONCENTR,			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
0	196	1.25×10^9	25	146	9.29×10^8	11,51	11,51	0	
50	139	8.81×10^8	47	89	5.65×10^8	11,51	5,75	4.82×10^5	C
60	127	8.08×10^8	51	77	4.92×10^8	11,51	4,60	4.82×10^5	C
70	116	7.35×10^8	56	66	4.10×10^8	11.51	3.45	4.82×10^5	C
80	104	6.63×10^8	60	55	3.46×10^8	11,51	2,30	$6,77 \times 10^5$	C
84	100	6.33×10^8	62	50	3.17 10^8	11.51	1,84	$8,17$ 10^5	C
86	97	6.19×10^8	63	48	3.03×10^8	11.51	1,61	8.88×10^5	C
88	95	6.04×10^8	64	45	2.88×10^8	11.51	1,38	9.60×10^5	C
98	93	5.90×10^8	64	43	2.73×10^8	11.51	1,15	$1,03 \times 10^6$	C
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	88	5.61×10^8	66	38	2.44×10^8	11.51	0,69	2.94×10^6	I
95	--	--	--	--	--	--	--	--	
96	86	5.46×10^8	67	36	2.30×10^8	11.51	0,46	7.04×10^6	R
97	--	--	--	--	--	--	--	--	
98	84	5.31×10^8	68	34	2.15×10^8	11.51	0,23	7.14×10^6	R
99	83	5.24×10^8	68	33	2.08×10^8	11.51	0.12	7.18×10^6	R

* C = Coagulation
I = Ion Exchange
R = Reverse Osmosis

Table F-1 (Con't)

Hypothetical STRATEGY: All MGMNT

System Total: 1.66×10^{9}

Strategy Total: 9.24×10^{8}

% EFF: 44

TREAT % removal	EFF P		System % removal	A EFF P		CONCENTR.		COST $/yr	Treatment Process*
	Eut	g yr		Eut	g/yr	Before	After		
0	86	5.41×10^{8}	67	81	5.14×10^{8}	7.51	7.51	0	
50	52	3.28×10^{8}	80	48	3.02×10^{8}	7.51	3.76	2.92×10^{5}	C
60	45	2.86×10^{8}	83	41	2.59×10^{8}	7.51	3.01	2.92×10^{5}	C
70	38	2.43×10^{8}	85	34	2.17×10^{8}	7.51	2.25	2.92×10^{5}	C
80	32	2.01×10^{8}	88	27	1.74×10^{8}	7.51	1.50	4.07×10^{5}	C
84	29	1.84×10^{8}	89	25	1.57×10^{8}	7.51	1.20	4.92×10^{5}	C
86	28	1.75×10^{8}	89	23	1.49×10^{8}	7.51	1.05	5.34×10^{5}	C
88	26	1.67×10^{8}	90	22	1.40×10^{8}	7.51	0.90	2.55×10^{6}	I
90	25	1.58×10^{8}	90	21	1.32×10^{8}	7.51	0.75	2.55×10^{6}	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	22	1.41×10^{8}	92	18	1.15×10^{8}	7.51	0.45	6.38×10^{6}	R
95	--	--	--	--	--	--	--	--	
96	21	1.33×10^{8}	92	17	1.06×10^{8}	7.51	0.30	6.47×10^{6}	R
97	--	--	--	--	--	--	--	--	
98	20	1.24×10^{8}	93	15	9.75×10^{7}	7.51	0.15	6.56×10^{6}	R
99	19	1.20×10^{8}	93	15	9.32×10^{7}	7.51	0.08	6.60×10^{6}	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-1 (Con't)

Hypothetical STRATEGY: DOMDET

System Total: 1.66×10^9

Strategy Total: 1.35×10^9

% EFF: 19

TREAT % removal	EFF P Eut	EFF P g/yr	System % removal	A EFF P Eut	A EFF P g/yr	CONCENTR. Before	CONCENTR. After	COST $/yr	Treatment Process*
0	164	1.04×10^9	37	114	7.25×10^8	7.37	7.37	--	
50	127	8.08×10^8	51	77	4.91×10^8	7.37	3.69	3.18×10^5	C
60	120	7.61×10^8	54	70	4.45×10^8	7.37	2.95	3.18×10^5	C
70	112	7.14×10^8	57	63	3.98×10^8	7.37	2.21	3.18×10^5	C
80	105	6.68×10^8	60	55	3.51×10^8	7.37	1.47	4.44×10^5	C
84	102	6.49×10^8	61	52	3.33×10^8	7.37	1.18	5.37×10^5	C
86	101	6.40×10^8	61	51	3.23×10^8	7.37	1.03	5.83×10^5	C
88	99	6.30×10^8	62	49	3.14×10^8	7.37	0.88	2.77×10^6	I
90	98	6.21×10^8	63	48	3.05×10^8	7.37	0.74	2.77×10^6	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	95	6.02×10^8	64	45	2.86×10^8	7.37	0.44	6.95×10^6	R
95	--	--		--	--	--	--	--	
96	93	5.93×10^8	64	44	2.77×10^8	7.37	0.29	7.04×10^6	R
97	--	--	--	--	--	--	--	--	
98	92	5.84×10^8	65	42	2.67×10^8	7.37	0.15	7.14×10^6	R
99	91	5.79×10^8	65	41	2.63×10^8	7.37	0.07	7.18×10^6	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-1 (Con't)

System Total: 1.66×10^9

Hypothetical STRATEGY: TREAT

% EFF: 0%

Strategy Total: 1.66×10^9

TREAT	EFF P			A EFF P		CONCENTR.		COST	Treatment
% removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	$/yr	Process*
0	214	1.46×10^9	18.1	164	1.04×10^9	12.42	12.42	--	
50	152	9.67×10^8	41.7	103	6.51×10^8	12.42	6.21	5.18×10^5	C
60	140	8.89×10^8	46.4	90.1	5.72×10^8	12.42	4.97	5.18×10^5	C
70	128	8.10×10^8	51.2	78	4.94×10^8	12.42	3.72	5.18×10^5	C
80	115	7.32×10^8	55.9	65	4.15×10^8	12.42	2.48	7.28×10^5	C
84	110	7.00×10^8	57.8	60	3.84×10^8	12.42	1.99	8.79×10^5	C
86	--	--	--	--	--	-	--	--	
88	105	6.68×10^8	59.8	55	3.52×10^8	12.42	1.49	1.03×10^6	C
90	--	--	--	--	--	--	--	--	
92	100	6.37×10^8	61.6	51	3.21×10^8	12.42	0.99	3.06×10^6	I
93	99	6.29×10^8	62.1	49	3.13×10^8	12.42	0.87	3.09×10^6	I
94	98	6.22×10^8	62.5	48	3.05×10^8	12.42	0.74	3.11×10^6	I
95	97	6.14×10^8	63.0	47	2.97×10^8	12.42	0.62	3.14×10^6	R
96		6.06×10^8	63.5	46	2.89×10^8	12.42	0.50	7.04×10^6	R
97	94	5.98×10^8	64.0	44	2.82×10^8	12.42	0.37	7.09×10^6	R
98	93	5.90×10^8	64.4	43	2.74×10^8	12.42	0.25	7.14×10^6	R
99	92	5.82×10^8	64.9	42	2.66×10^8	12.42	0.12	7.18×10^6	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-2

MICHIGAN
(100 m)

STRATEGY: NIL

System Total: 1.77×10^{10}

Strategy Total: 1.77×10^{10}

% EFF: 0.00

TREAT % removal	EFF P			A EFF P		CONCENTR.		COST $/yr	Treatment Process*
	Eut	g/yr	System % removal	Eut	g/yr	Before	After		
0	3.92	1.74×10^{10}	1.7	2.60	1.16×10^{10}	5.33×10^{9} 11.18	5.33×10^{9} 11.18	0.00	
50	3.32	1.47×10^{10}	17	2.00	8.91×10	5.33×10^{9} 11.18	5.33×10^{9} 5.59	3.33×10^{6}	
60	3.20	1.42×10^{10}	20	1.88	8.38×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 4.47	3.33×10^{6}	
70	3.08	1.37×10^{10}	23	1.76	7.85×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 3.35	3.33×10^{6}	
80	2.96	1.31×10^{10}	26	1.64	7.31×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 2.24	4.73×10^{6}	
84	2.91	1.29×10^{10}	27	1.60	7.10×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 1.79	5.75×10^{6}	
86	--	--	--	--	--	--	--	--	
88	2.86	1.27×10^{10}	28	1.55	6.89×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 1.34	6.78×10^{6}	
90	--	--	--	--	--	--	--	--	
92	2.81	1.25×10^{10}	29	1.50	6.67×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.89	1.39×10^{7}	
93	2.80	1.25×10^{10}	29	1.49	6.62×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.78	1.40×10^{7}	
94	2.79	1.24×10^{10}	30	1.48	6.57×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.67	1.41×10^{7}	
95	2.78	1.23×10^{10}	31	1.46	6.51×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.56	1.43×10^{7}	
96	2.76	1.23×10^{10}	31	1.45	6.46×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.45	4.03×10^{7}	
97	2.75	1.22×10^{10}	31	1.44	6.41×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.34	4.06×10^{7}	
98	2.74	1.22×10^{10}	31	1.43	6.35×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.22	4.09×10^{7}	
99	2.73	1.21×10^{10}	31	1.42	6.30×10^{9}	5.33×10^{9} 11.18	5.33×10^{9} 0.11	4.13×10^{7}	

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-2 (Con't)

MICHIGAN
(100 m)

STRATEGY: DOM DET

System Total: 1.77×10^{10}

Strategy Total: 1.54×10^{10}

% EFF: 13%

	EFF P			A EFF P		CONCENTR.			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
0	3.40	1.51×10^{10}	15	2.09	9.27×10^{9}	3.03×10^{9} 6.35	3.03×10^{9} 6.35	0.00	C
50	3.06	1.36×10^{10}	23	1.75	7.76×10^{9}	3.03×10^{9} 6.35	1.51×10^{9} 3.18	1.93×10^{6}	C
60	2.99	1.33×10^{10}	25	1.68	7.46×10^{9}	3.03×10^{9} 6.35	1.21×10^{9} 2.54	1.93×10^{6}	C
70	2.92	1.30×10^{10}	26	1.61	7.16×10^{9}	3.03×10^{9} 6.35	9.08×10^{8} 1.91	1.93×10^{6}	C
80	2.85	1.27×10^{10}	28	1.54	6.85×10^{9}	3.03×10^{9} 6.39	6.06×10^{8} 1.27	2.72×10^{6}	C
84	2.83	1.26×10^{10}	29	1.51	6.73×10^{9}	3.03×10^{9} 6.35	4.84×10^{8} 1.02	3.31×10^{6}	C
86	2.81	1.25×10^{10}	29	1.50	6.67×10^{9}	3.03×10^{9} 6.35	4.24×10^{8} 0.89	1.36×10^{7}	I
88	2.80	1.24×10^{10}	30	1.49	6.61×10^{9}	3.03×10^{9} 6.35	3.63×10^{8} 0.76	1.36×10^{7}	I
90	2.79	1.24×10^{10}	30	1.47	6.55×10^{9}	3.03×10^{9} 6.35	3.02×10^{8} 0.64	1.36×10^{7}	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	2.76	1.23×10^{10}	31	1.45	6.43×10^{9}	3.03×10^{9} 6.[illegible]	1.82×10^{8} 0.38	3.96×10^{7}	R
95	--	--	--	--	--	--	--	--	
96	2.74	1.22×10^{10}	31	1.43	6.37×10^{9}	3.03×10^{9} 6.35	1.21×10^{8} 0.25	4.03×10^{7}	R
97	--	--	--	--	--	--	--	--	
98	2.73	1.21×10^{10}	32	1.42	6.31×10^{9}	3.03×10^{9} 6.35	6.06×10^{7} 0.13	4.09×10^{7}	R
99	2.72	1.21×10^{10}	32	1.41	6.28	3.03×10^{9} 6.35	3.03×10^{7} 0.06	4.13×10^{7}	R

* C = Coagulation
I = Ion Exchange
R = Reverse Osmosis

Table F-2 (Con't)

MICHIGAN (100 m)	STRATEGY: IN DET	System Total: 1.77×10^{10}	
		Strategy Total: 1.71×10^{10}	% EFF: 3.4%

TREAT % removal	EFF P		System % removal	A EFF P		CONCENTR.		COST $/yr	Treatment Process*
	Eut	g/yr		Eut	g/yr	Before	After		
0	3.78	1.68×10^{10}	5.1	2.47	11.0×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 10.56	0.00	
50	3.22	1.43×10^{10}	19.2	1.90	8.47×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 5.28	3.15×10^{6}	C
60	3.10	1.38×10^{10}	22.0	1.79	7.97×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 4.22	3.15×10^{6}	C
70	2.99	1.33×10^{10}	24.9	1.68	7.46×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 3.17	3.15×10^{6}	C
80	2.88	1.28×10^{10}	27.7	1.57	6.96×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 2.11	4.47×10^{6}	C
84	2.83	1.26×10^{10}	28.8	1.52	6.76×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 1.69	5.44×10^{6}	C
86	2.81	1.25×10^{10}	29.4	1.50	6.66×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 1.48	5.93×10^{6}	C
88	2.79	1.24×10^{10}	29.9	1.47	6.56×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 1.27	6.41×10^{6}	C
90	2.76	1.23×10^{10}	30.5	1.45	6.46×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 1.06	6.89×10^{6}	C
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	2.72	1.21×10^{10}	31.6	1.41	6.26×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 0.63	1.36×10^{7}	I
95	--	--	--	--	--	--	--	--	
96	2.70	1.20×10^{10}	32.2	1.38	6.15×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 0.42	4.03×10^{7}	R
97	--	--	--	--	--	-	--	--	
98	2.67	1.19×10^{10}	32.8	1.36	6.05×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 0.21	4.09×10^{7}	R
99	2.66	1.18×10^{10}	33.3	1.35	6.00×10^{9}	5.03×10^{9} 10.56	5.03×10^{9} 0.11	4.13×10^{7}	R

C = Coagulation

I = Ion Exchange

R - Reverse Osmosis

Table F-2 (Con't)

MICHIGAN
100 m)

STRATEGY: 10% P

System Total: 1.77×10^{10}
Strategy Total: 1.31×10^{10}

% EFF: 26.0

TREAT % removal	EFF P Eut	EFF P g/yr	System % removal	A EFF P Eut	A EFF P g/yr	CONCENTR. Before	CONCENTR. After	COST $/yr	Treatment Process*
0	2.88	12.8×10^9	27.7	2.60	1.16×10^{10}	5.33×10^9 11.18	5.33×10^9 11.18	0.00	
50	2.28	10.1×10^9	42.[illegible]	2.00	8.91×10^9	5.33×10^9 11.18	2.66×10^9 5.59	3.33×10^6	C
60	2.16	9.59×10^9	45.8	1.88	8.38×10^9	5.33×10^9 11.18	2.13×10^9 4.47	3.33×10^6	C
70	2.04	9.06×10^9	48.8	1.76	7.85×10^9	5.33×10^9 11.18	1.60×10^9 3.35	3.33×10^6	C
80	1.92	8.52×10^9	51.9	1.64	7.31×10^9	5.33×10^9 11.18	1.07×10^9 2.24	4.73×10^6	C
84	1.87	8.31×10^9	53.1	1.60	7.10×10^9	5.33×10^9 11.18	8.52×10^8 1.79	5.75×10^6	C
86	1.84	8.21×10^9	53.6	-- 1.57	-- 6.99	--	1.56 --	6.27×10^6 --	C
88	1.82	8.10×10^9	54.2	1.55	6.89×10^9	5.33×10^9 11.18	6.39×10^8 1.34	6.78×10^6	C
90	1.80	7.99×10^9	54.9	1.52 --	6.78 --	11.18 --	1.12 --	7.29×10^6 --	C
92	--	--	-	1.50	6.67×10^9	5.33×10^9 11.18	4.26×10^8 0.89	1.39×10^7	
93	--		-	1.49	6.62×10^9	5.33×10^9 11.18	3.73×10^8 0.78	1.40×10^7	
94	1.75	7.78×10^9	56.0	1.48	6.57×10^9	5.33×10^9 11.18	3.20×10^8 0.67	1.41×10^7	
95	--	--		1.46	6.51×10^9	5.33×10^9 11.18	2.66×10^8 0.56	1.43×10^7	
96	1.73	67×10^9	56.	1.45	6.46×10^9	5.33×10^9 11.18	2.13×10^8 0.45	4.03×10^7	
97	--	--	--	1.44	6.41×10^9	5.33×10^9 11.18	1.60×10^8 0.34	4.06×10^7	
98	1.70	7.56×10^9	5[illegible].3	1.43	6.35×10^9	5.33×10^9 11.18	1.07×10^8 0.22	4.09×10^7	
99	1.69	7.51×10^9	57.6	1.42	6.30×10^9	5.33×10^9 11.18	5.33×10^8 0.11	4.13×10^7	

* C = Coagulation
I = Ion Exchange
R = Reverse Osmosis

Table F-2 (Con't)

MICHIGAN
(100 m)

STRATEGY: ALL

System Total: 1.77×10^{10}

Strategy Total: 9.83×10^9

% EFF: 44.5

TREAT % removal	EFF P Eut	EFF P g/yr	System % removal	A EFF P Eut	A EFF P g/yr	CONCENTR. Before	CONCENTR. After	COST $/yr	Treatment Process
0	2.13	9.46×10^9	46.6	1.87	8.32×10^9	2.81×10^9 7.04	2.81×10^9 7.04	0.00	
50	[illegible].81	8.06×10^9	54.5	1.56	6.91×10^9	2.81×10^9 7.04	2.81×10^9 3.52	1.80×10^6	C
60	1.75	7.77×10^9	56.1	1.49	6.63×10^9	2.81×10^9 7.04	2.81×10^9 2.82	1.80×10^6	C
70	1.69	7.49×10^9	57.7	1.43	6.35×10^9	2.81×10^9 7.04	2.81×10^9 2.11	1.80×10^6	C
80	1.62	7.21×10^9	59.3	1.37	6.07×10^9	2.81×10^9 7.04	2.81×10^9 1.41	2.53×10^6	C
84	1.[illegible]0	7.10×10^9	59.9	1.34	5.96×10^9	2.81×10^9 7.04	2.81×10^9 1.13	3.08×10^6	C
86	1.58	7.04×10^9	60.2	1.33	5.90×10^9	2.81×10^9 7.04	2.81×10^9 0.99	1.19×10^7	I
88	1.57	6.99×10^9	60.5	1.32	5.85×10^9	2.81×10^9 7.04	2.81×10^9 0.84	1.19×10^7	I
90	1.56	6.93×10^9	[illegible].8	1.30	5.79×10^9	2.81×10^9 7.04	2.81×10^9 0.70	1.19×10^7	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	1.53	6.82×10^9	61.5	1.28	5.68×10^9	2.81×10^9 7.04	2.81×10^9 0.42	3.38×10^7	R
95	--	-	--	--	--	--	--	--	
96	1.52	6.76×10^9	61.8	1.26	5.62×10^9	2.81×10^9 7.04	2.81×10^9 0.28	3.43×10^7	R
97	--	--	--	--	--	--	-	--	
98	1.51	6.71×10^9	62.1	1.25	5.57×10^9	2.81×10^9 7.04	2.81×10^9 0.14	3.49×10^7	R
99	1.50	6.68×10^9	63.3	1.25	5.54×10^9	2.81×10^9 7.04	2.81×10^9 0.07	3.52×10^7	R

C - Coagulation
I - Ion Exchange
R - Reverse Osmosis

Table F-2 (Con't)

MICHIGAN
(100 m)

STRATEGY: ALL EX FAC_2

System Total: 1.77×10^{10}

Strategy Total: 9.83×10^9

% EFF: 44.5

TREAT % removal	EFF P			A EFF P		CONCENTR.		COST $/yr	Treatment Process*
	Eut	g/yr	System % removal	Eut	g/yr	Before	After		
0	2.13	9.46×10^9	46.6	1.87	8.32×10^9	2.61×10^9 6.09	2.61×10^9 6.09	0.00	
50	1.83	8.15×10^9	54.[illegible]	1.58	7.01×10^9	2.61×10^9 6.09	2.61×10^9 3.05	1.67×10^6	C
60	1.78	7.89×10^9	55.4	1.52	6.75×10^9	2.61×10^9 6.09	2.61×10^9 2.44	1.67×10^6	C
70	1.72	7.63×10^9	56.9	1.46	6.49×10^9	2.61×10^9 6.09	2.61×10^9 1.83	1.67×10^6	C
80	1.66	7.37×10^9	58.4	1.40	6.23×10^9	2.61×10^9 6.09	2.61×10^9 1.22	2.36×10^6	C
84	1.63	7.27×10^9	58.9	1.38	6.12×10^9	2.61×10^9 6.09	2.61×10^9 0.97	1.25×10^7	I
86	1.62	7.21×10^9	59.3	1.37	6.07×10^9	2.61×10^9 6.09	2.61×10^9 0.85	1.25×10^7	I
88	1.61	7.16×10^9	59.5	1.35	6.02×10^9	2.61×10^9 6.09	2.61×10^9 0.73	1.25×10^7	I
90	1.60	7.11×10^9	59.8	1.34	5.97×10^9	2.61×10^9 6.09	2.61×10^9 0.61	1.25×10^7	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	1.58	7.01×10^9	60.4	1.32	5.86×10^9	2.61×10^9 6.09	2.61×10^9 0.37	3.60×10^7	R
95	--	--	--	--	--	--	--	--	
96	1.56	6.95×10^9	60.7	1.31	5.81×10^9	2.61×10^9 6.09	2.61×10^9 0.24	3.66×10^7	R
97	-	--	--	--	--	--	--	--	
98	1.55	6.90×10^9	61.0	1.30	5.76×10^9	2.61×10^9 6.09	2.61×10^9 0.12	3.72×10^7	R
99	1.55	6.87×10^9	61.2	1.29	5.73×10^9	2.61×10^9 6.09	2.61×10^9 0.06	3.75×10^7	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-3

Lake Erie (20 m) STRATEGY ALL

System Total: 2.86×10^{10}

Strategy Total: 1.65×10^{10}

% EFF: 42.3

TREAT % removal	EFF P Eut	EFF P g/yr	EFF P System % removal	A EFF P Eut	A EFF P g/yr	CONCENTR. Before	CONCENTR. After	COST $ yr	Treatment Process*
		10^9			10^9	9.73×10^9	9.73×10^9		
0	24	16.1	43.7	21	14.3	6.76	6.76	0.00	
50	17	11.3	60.4	14	9.39	6.76	3.38	6.00×10^6	C
60	15	10.3	63.9	13	8.42	6.76	2.70	6.00×10^6	C
70	14	9.33	67.3	11	7.45	6.76	2.03	6.00×10^6	C
80	13	8.35	70.8	10	6.48	6.76	1.3[illegible]	8.53×10^6	C
84	12	7.96	72.1	9	6.09	6.76	1.08	1.04×10^7	C
86	12	7.77	72.[illegible]	9	5.89	6.76	0.95	3.23×10^7	I
88	11	7.57	73.5	9	5.70	6.76	0.81	3.23×10^7	I
90	11	7.38	74.2	8	5.50	6.76	0.68	3.23×10^7	I
92	--	--	--	--	--	--	--	--	
93		--		--	--	--	--	--	
94	10	6.99	75.6	8	5.11	6.76	0.41	1.13×10^8	R
95	--					-	--	--	
96	10	6.80	76.2	7	4.92	6.76	0.27	1.15×10^8	R
97	-	--	--	-	-		--	--	
98	10	6.60	76.9	7	4.72	6.76	0.14	1.17×10^8	R
99	10	6.50	77.3	7	4.63	6.76	0.07	1.18×10^8	R

C = Coagulation

I = Ion Exchange

R = Reverse Osmos

Table F-3 (Con't)

Erie STRATEGY: All Ex FAC2

System Total: 2.86×10^{10}

Strategy Total: 1.65×10^{10}

% EFF: 42.3

	EFF P			A EFF P		CONCENTR.			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
		10^9			10^9	9.03×10^9	9.03×10^9		
0	24	16.1	43.7	21	16.1	6.28	6.28	0.00	
50	17	11.6	59.4	15	9.74	6.28	3.14	5.57×10^6	C
60	16	10.7	62.6	13	8.84	6.28	2.51	5.57×10^6	C
70	15	9.82	65.7	12	7.94	6.28	1.88	5.57×10^6	C
80	13	8.91	68.8	11	7.03	6.28	1.26	7.93×10^6	C
84	13	8.55	70.1	10	6.67	6.28	1.00	9.67×10^6	C
86	13	8.37	70.7	10	6.49	6.28	0.88	3.23×10^7	I
88	12	8.19	71.4	9	6.31	6.28	0.75	3.23×10^7	I
89	12	8.01	72.0	9	6.13	6.28	0.63	3.23×10^7	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	11	7.65	72.3	9	5.77	6.28	0.38	1.13×10^8	R
95	--	--	--	--	--	--	--	--	
96	11	7.47	73.9	8	5.59	6.28	0.25	1.15×10^8	R
97	--	--	--	--	--	--	--	--	R
98	11	7.29	74.5	8	5.41	6.28	0.13	1.17×10^8	R
99	11	7.20	74.8	8	5.32	6.28	0.06	1.18×10^8	R

C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-3 (Con't)

Erie STRATEGY: INDET

System Total: 2.86×10^{10}

Strategy Total: 2.66×10^{10}

% EFF: 7.0

	EFF P			A EFF P		CONCENTR.			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
0	39	10^{10} 2.63	8.04	35	10^{10} 2.35	1.76×10^{10} 10.98	1.76×10^{10} 10.98	0.00	
50	26	1.75	38.8	22	1.47	10.98	5.49	1.08×10^7	C
60	24	1.57	45.1	19	1.29	10.98	4.39	1.08×10^7	C
70	21	1.39	51.4	17	1.11	10.98	3.29	1.08×10^7	C
80	18	1.22	57.3	14	.937	10.98	2.20	1.54×10^7	C
84	17	1.15	59.8	13	.867	10.98	1.76	1.86×10^7	C
86	17	1.11	61.2	12	.832	1.54	1.54	2.04×10^7	C
88	16	1.08	62.2	12	.796	10.98	1.32	2.21×10^7	C
90	16	1.04	63.6	11	.761	10.98	1.10	2.38×10^7	C
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	-	--	
94	15	.972	66.0	10	.690	10.98	0.66	3.61×10^7	I
95	--	--	--	--	--	--	--	--	
96	14	.936	67.3	10	.655	10.98	0.44	1.27×10^8	R
97	--	--	--	--	--	--	--	--	
98	13	.901	68.5	9	.620	10.98	0.22	1.29×10^8	R
99	13	.883	69.1	9	.602	10.98	0.11	1.31×10^8	R

C = Coagulation
I = Ion Exchange
R = Reverse Osmosis

Table F-3 (Con't)

Erie   STRATEGY: DOM DET   System Total: 2.86×10^{10} Strategy Total: 2.05×10^{10} % EFF: 28.3

	EFF P			A EFF P		CONCENTR.			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
		10^{10}			10^{9}	1.05×10^{10}	1.05×10^{10}		
0	30	2.01	29.7	26	17.3	6.52	6.52	0.00	
50	22	1.49	47.9	18	12.1	6.52	3.26	6.44×10^{6}	C
60	21	1.39	51.4	17	11.1	6.52	2.61	6.44×10^{6}	C
70	19	1.28	55.2	15	10.0	6.52	1.96	6.44×10^{6}	C
80	18	1.18	58.7	13	8.96	6.52	1.30	9.18×10^{6}	C
84	17	1.14	60.1	13	8.54	6.52	1.04	1.12×10^{7}	C
86	17	1.11	61.2	12	8.33	6.52	0.91	3.52×10^{7}	I
88	16	1.09	61.9	12	8.12	6.52	0.78	3.52×10^{7}	I
90	16	1.07	62.6	12	7.91	6.52	0.65	3.52×10^{7}	I
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	15	1.03	64.0	11	7.49	6.52	0.39	1.25×10^{8}	R
95	--	--	--		--	--	--	--	
96	15	1.01	64.7	11	7.28	6.52	0.26	1.27×10^{8}	R
97	--	--	--	--	--	--	--	--	
98	15	.989	65.4	11	7.08	6.52	0.13	1.29×10^{8}	R
99	15	.978	65.8	10	6.97	6.52	0.07	1.31×10^{8}	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-3 (Con't)

Erie STRATEGY: TREAT

System Total: 2.86×10^{10}

Strategy Total: 2.86×10^{10}

% EFF 0

TREAT % removal	EFF P			A EFF P		CONCENTR.		COST $/yr	Treatment Process*
	Eut	g/yr	System % removal	Eut	g/yr	Before	After		
0	42	10^{10} 2.83	1.04	38	10^{10} 2.55	1.87×10^{10} 11.61	1.87×10^{10} 11.61	0.00	
50	28	1.90	33.5	24	1.62	11.61	5.81	1.14×10^7	C
60	26	1.71	40.2	21	1.43	11.61	4.65	1.14×10^7	C
70	23	1.53	46.5	18	1.25	11.61	3.48	1.14×10^7	C
80	20	1.34	53.1	16	1.06	11.61	2.32	1.63×10^7	C
84	19	1.27	55.6	15	.985	11.61	1.86	1.98×10^7	C
86		--	--	--	--	--	--	--	
88	18	1.19	58.4	14	.910	11.61	1.39	[illegible].34 $\times 10^7$	C
90	--	-	--	--	--	--	--	--	
92	16	1.12	60.8	12	.836	11.61	0.93	3.71×10^7	I
93	16	1.10	61.5	12	.817	11.61	0.81	3.75×10^7	I
94	16	1.08	62.2	12	.799	11.61	0.70	3.78×10^7	I
95	16	1.06	62.9	12	.780	11.61	0.58	3.81×10^7	I
96	16	1.04	63.6	11	.761	11.61	0.46	1.27×10^8	R
97	16	1.02	64.3	11	.743	11.61	0.35	1.28×10^8	R
98	15	1.01	64.7	11	.724	11.61	0.23	1.29×10^8	R
99	15	.986	65.5	11	.705	11.61	0.12	1.31×10^8	R

C - Coagulation

I = Ion Exchange

R = Reverse Osmosis

Table F-3 (Con't)

Erie STRATEGY: 10% P

System Total: 2.86 x 10^{10}

Strategy Total: 2.77 x 10^{10}

% EFF: 3.1

	EFF P			A EFF P		CONCENTR.			
TREAT % removal	Eut	g/yr	System % removal	Eut	g/yr	Before	After	COST $/yr	Treatment Process*
0	41	10^{10} 2.74	4.2	38	10^{10} 2.55	1.87 x 10^{10} 11.61	1.87 x 10^{10} 11.61	0.00	
50	27	1.81	36.7	24	1.62	11.61	5.81	1.14 x 10^7	C
60	24	1.62	43.4	21	1.43	11.61	4.65	1.14 x 10^7	C
70	22	1.44	49.7	19	1.25	11.61	3.48	1.14 x 10^7	C
80	19	1.25	56.3	16	1.06	11.61	2.32	1.63 x 10^7	C
84	18	1.18	58.7	15	.985	11.61	1.86	1.98 x 10^7	C
86	17	1.14	60.1	14	.948	11.61	1.63	2.16 x 10^7	C
88	16	1.10	61.5	14	.910	11.61	1.39	2.34 x 10^7	C
90	16	1.07	62.6	13	.873	11.61	1.16	2.52 x 10^7	C
92	--	--	--	--	--	--	--	--	
93	--	--	--	--	--	--	--	--	
94	15	.990	65.4	12	.799	11.61	0.70	3.78 x 10^7	I
95	--	--	--	--	--	--	--	--	
96	14	.953	66.7	11	.761	11.61	0.46	1.27 x 10^8	R
97	--	--	--	--	--	--	--	--	
98	14	.916	68.0	11	.724	11.61	0.23	1.29 x 10^8	R
99	13	.897	68.7	11	.705	11.61	0.12	1.31 x 10^8	R

* C = Coagulation

I = Ion Exchange

R = Reverse Osmosis

*U.S. GOVERNMENT PRINTING OFFICE: 1974 546-316/268 1-3